COST EFFECTIVENESS OF MOBILE-SOURCE POLLUTION CONTROL SYSTEMS

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RECYCLABLE

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EXECUTIVE SUMMARY

In Canada, vehicles emit significant quantities of lead, nitrogen oxides, hydrocarbons, carbon monoxide, sulphur oxides, and particulates in to the environment. Revised federal regulations have been promulgated with the intent to reduce the magnitude of light-duty vehicular emissions in Canada. These new emission standards have been in effect since September 1, 1987, and were initiated for the 1988 model-year cars and light-duty trucks.

The revised federal standards for the allowable emissions from light duty vehicles are as follows:

- the amount of lead allowed in leaded gasoline is now 0.29 grams per litre,
- by 1990, the amount of lead used in gas will be virtually eliminated,
- the NO_x automobile emission standard is now 1.0 gram per mile driven (gpm),
- the hydrocarbon emission standards is now 0.41 gpm, and
- the carbon monoxide emission standards is now 3.4 gpm.

These emission standards will be achieved through the use of improved engine design and the installation of pollution control systems. To determine the most effective way to regulate air emissions of all sources in Ontario, the cost of these vehicle emission controls must be calculated. This study has found that during the years 1984 to 1988, it was estimated that $1408 million (1987 $ Can) was spent on pollution control equipment on motor vehicles in Ontario. For the whole of Canada, this value was $3117 million (1987 $ Can).

The major mobile pollution sources are:

- light duty vehicles (cars and trucks), and
- heavy duty trucks.

Currently, there are about 5 million cars and light duty trucks and 73,000 heavy duty vehicles in Ontario. This study projects, however, by the year

2002 there will be 8 million cars and light duty trucks and 155,000 heavy duty vehicles on the road. Additional mobile pollution sources that were investigated in this study include:

- other transportation sources; railways, aircraft, and shipping,
- household sources; lawnmowers, snowmobiles, and boats, and
- farm equipment; tractors, combines, and harvesters.

It is notable that vehicle sales and populations are closely connected to global economic trends. The inherent difficulty in making detailed economic projections precludes an accurate estimate of future vehicle populations. The estimates developed in this study were projected from Ontario motor vehicle population statistics for the years 1983 - 88.

In the year 1988, light duty vehicles were the major mobile source of:

- nitrogen oxides (NO_x); 54% of the total,
- carbon monoxide (CO); 72%, and
- hydrocarbons; 44%

Other transportation sources (railways, aircraft, and ships) contributed the major mobile portion of oxides of sulphur (SO_x) with 85% of the total. Farm equipment contributed 46% of the total mobile aldehyde emissions. The major mobile source of particulates was heavy duty diesel vehicles with 59.8% of the total.

In order to estimate the cost-effectiveness of the emission standards, it was necessary to project the costs of complying with the standards and the expected pollutant reduction. Two scenarios were considered for each class of vehicle. They were:

i) The effect of the implementation of the 1987 standards for light-duty vehicles and the 1988 standards for heavy-duty vehicles were projected to the year 2002. The costs of the necessary pollution control equipment, and the expected pollutant reduction were then calculated.

ii) In the second scenario, a future control option/equipment was postulated, and the costs of the associated control technology, and pollutant reduction were estimated.

In each scenario, the net present values of the total equipment costs and of the operating costs for the years 1988 to 2002 were estimated. In each case this monetary value was divided by the projected emission reduction the technology would provide in tonnes of pollutant per year. The resultant value represented the present value of the total cost per tonne of pollutant removed. These costs are listed in Table A. All the costs were calculated in 1987 Canadian dollars.

On the basis of this study the total annual mobile emission levels will increase significantly in the future. By 2002, mobile pollution emissions will increase by the following amounts, from the 1987 base year:

- hydrocarbons; 11%,
- sulphur oxides; 17%,
- particulates; 36%, and
- aldehydes; 5%.

Only nitrogen oxides emissions are expected to decrease but only by a factor of 11%. Carbon monoxide emissions are not expected to change (0.1% increase by 2002).

Table B lists the estimated annual emission levels of these pollutants.

This study indicates that although some major reductions are expected in the emissions per vehicle, there is a net increase in the total mobile source pollution budget. The primary cause of this increase is the substantial rise in the number of vehicles operating in the province over the 15 year study period.

TABLE A.

TOTAL PROJECTED COSTS OF POLLUTION CONTROL SYSTEMS
1988-2002
(1987 $ Can)

Vehicle Class	Case	Total Capital and Operating Cost ($m)	Pollutant Controlled	Total Cost of Pollutant Reduction ($/tonne)
Light Duty Gasoline Vehicle	A	$1,209	NOx	$693
			CO	$58
			Hydrocarbons	$754
	B	$2,577	NOx	$838
			CO	$119
			Hydrocarbons	$1,475
Light Duty Diesel Vehicle	A	$41	NOx	$3,618
			Particulates	$3,116
	B	$66	NOx	$3,618
			Particulates	$5,491
Heavy Duty Gasoline Vehicle	A	$7	NOx	$4,021
			CO	$78
			Hydrocarbons	$149
	B	$33	NOx	$5,655
			CO	$263
			Hydrocarbons	$645
Heavy Duty Diesel Vehicle	A	$92	NOx	$435
			Particulates	$21,221
	B	$169	NOx	$435
			Particulates	$19,106

TABLE B: ESTIMATED ANNUAL POLLUTANT EMISSION LEVELS

Pollutant	Year	Annual Emission Level (tonnes/year)
Nitrogen Oxides (NO_x)	1988	272,134
	2002	240,922
Carbon Monoxide (CO)	1988	1,746,595
	2002	1,758,257
Hydrocarbons	1988	240,411
	2002	265,760
Particulates	1988	7,178
	2002	9,729
Sulphur Oxides (SO_x)	1988	15,799
	2002	18,441
Aldehydes	1988	1,652
	2002	1,731

1.0 INTRODUCTION

In Canada, vehicles emit significant quantities of lead, nitrogen oxides, hydrocarbons, carbon monoxide, sulphur oxides, and particulates. In addition many of the emitted gases are involved in the production of secondary pollutants such as ozone and acid rain. Revised federal regulations have been promulgated with the intent to significantly reduce the magnitude of vehicular emissions in Canada. These new emission standards have been in effect since September 1, 1987, and were initiated for the 1988 model-year cars and light-duty trucks.

Prior to the implementation of the revised emission standards, Environment Canada estimated the vehicular components contributing to the total air pollution burden as:

- lead - 60% of total emissions,
- nitrogen oxides - 20% of overall NO_x,
- hydrocarbons - 24% of total emissions, and
- carbon monoxide - 45% of total (human activity) emissions.

The revised federal standards reduced the amount of emissions as follows:

- the amount of lead allowed in leaded gasoline was reduced from 0.77 grams per litre to 0.29 grams per litre,
- by 1990, the amount of lead used in gas will be virtually eliminated,
- the NO_x automobile emission standard declined from 3.1 grams per mile driven (gpm) to 1.0 gpm,
- the hydrocarbon auto emission standard declined from 2.0 gpm to 0.41 gpm, and
- the carbon monoxide emission standard declined from 25 gpm to 3.4 gpm.

These emission reductions will be achieved through the use of improved engine design and the installation of pollution control systems. The most important of these control systems is the catalytic converter. The two-way or oxidation catalytic converter has been the most frequently used system, however as emissions standards become more stringent the use of the three-way catalytic converter is expected to increase.

To determine the most effective way to regulate air emissions of all sources in Ontario, the cost of vehicle emission controls must be evaluated. The technology and its effectiveness to reduce emissions or achieve emission standards must be weighed against their economic feasibility in the marketplace. In addition, the cost-effectiveness of vehicle emission control in Ontario must also be evaluated.

In order to evaluate the cost effectiveness of the vehicle emission control, this study was undertaken by MacLaren Plansearch for the Air Resources Branch of the Ontario Ministry of the Environment. Nine tasks were defined by the Ministry and were carried out. These included:

- a search of the current literature to determine what studies have been carried out on the subject (the resulting bibliography is presented at the end of the report).
- the identification of the total Ontario motor vehicle population of light and heavy duty gasoline and diesel vehicles,
- the identification of other miscellaneous mobile pollution sources such as household facilities, farm equipment and other transportation sources to determine their contribution to Ontario's total pollution burden,
- the identification of automotive pollution control systems and devices installed on light and heavy duty gasoline and diesel vehicles,
- the identification of the effects of tampering with the pollution

control systems on the vehicle operation,

- the identification of possible future pollution control systems and alternate fuel systems,

- the identification of the influence of market penetration on the availability of vehicle models in Canada,

- the identification of the capital costs, manufacturers' and consumers', of the pollution control systems being used,

- the identification of any variation in operating costs due to the pollution control systems, and

- the estimation of the cost of vehicle pollution control in Ontario and Canada for the last five years.

The information that was obtained during the execution of these tasks is presented in the following report.

2.0 IDENTIFICATION OF THE ONTARIO MOTOR VEHICLE POPULATION

2.1 Summary Of The Ontario Motor Vehicle Population

Eleven classes of motor vehicles were considered as sources of pollutants; these are listed in Table 2.1. The total and model year populations for 1984 to 1987 for each vehicle class was summarized from the Ontario Plate/Registrant/Vehicle report of 1987 [1] prepared by the Ontario Ministry of Transportation. A more detailed description of the procedures used in determining vehicle emissions and populations is provided in Section 2.2. At various stages of the analysis, linear regressions of the data were calculated. These linear regressions are summarized in Appendix A of the report.

For gasoline and diesel fueled passenger cars and trucks, it was assumed that the percentage of car and truck sales which were diesel or gasoline would remain constant in the future. For diesel light duty vehicles, this would be 1.5% of all passenger car sales and 6.5% of all light duty truck sales [20]. This assumption requires that efficient and durable particulate traps are developed which will consistently meet the more stringent particulate standards adopted in 1987. On the basis of conversations with officials from Environment Canada and the California Air Resources Board, it appears that better diesel control systems have been developed and that standards are being met [2,3]. Further improvements are being made to the traps as a result of continued research and development.

For heavy duty gasoline vehicles, it has been estimated that 41.6% of the heavy duty vehicle market will be held by gasoline vehicles. As well, the percentage of vehicles in the light and medium weight classes was assumed to remain constant at 77% and 23% respectively. It is notable that the heavy duty gasoline vehicle market is quite volatile due to the impact of global oil markets and economic recessions. Therefore it is difficult to estimate future usage of these vehicle classes with good precision [4].

TABLE 2.1.

MOTOR VEHICLE CLASSES

Light Duty Vehicles	- gasoline passenger cars
	- diesel passenger cars
	- gasoline light duty trucks
	- diesel light duty trucks
	- motorcycles
Heavy Duty Vehicles	- light heavy duty gasoline vehicles
	- medium heavy duty gasoline vehicles
	- light heavy duty diesel vehicles
	- medium heavy duty diesel vehicles
	- heavy heavy duty diesel vehicles
	- buses

Similarly, heavy duty diesel vehicles are assumed to capture 58.4% of the market now and in the future. Any growth in the diesel market due to a shift from gasoline to diesel vehicles has been neglected since it would be difficult to accurately estimate the extent of this trend [4].

To predict the future populations for the different vehicle classes, a linear regression based on the population of years 1984 to 1987 was used. This assumption ignored any cyclical changes due to economic conditions or the shift to diesel vehicles for heavy duty vehicles.

Figures 2.1 to 2.3 show the present and predicted total and model year vehicle populations for gasoline passenger cars and trucks, diesel passenger cars and trucks, heavy duty gasoline vehicles, and heavy duty diesel vehicles for the years from 1984 to 2002. Tables 2.2 to 2.5 present the data used to prepare the populations displayed in the figures. These populations will be used in Chapter 9 when projected costs of various pollution control systems are estimated.

Currently, there are about 5 million cars and light duty trucks, and 73,000 heavy duty vehicles on the road in Ontario. These projections estimate that by the year 2002, there could be nearly 8 million cars and light duty trucks on the road in Ontario. These could be joined by as many as 155,000 heavy duty vehicles.

Once again, it is important to note that future vehicle sales are influenced by a number of economic factors that cannot be estimated in a study of this limited scope.

2.2 Method Of Calculating Vehicle Pollutant Emissions

2.2.1 Passenger Cars (Gasoline): Calculation Of Emissions And Vehicle Populations

Emissions: These data was obtained from the Vehicle Emissions Section of

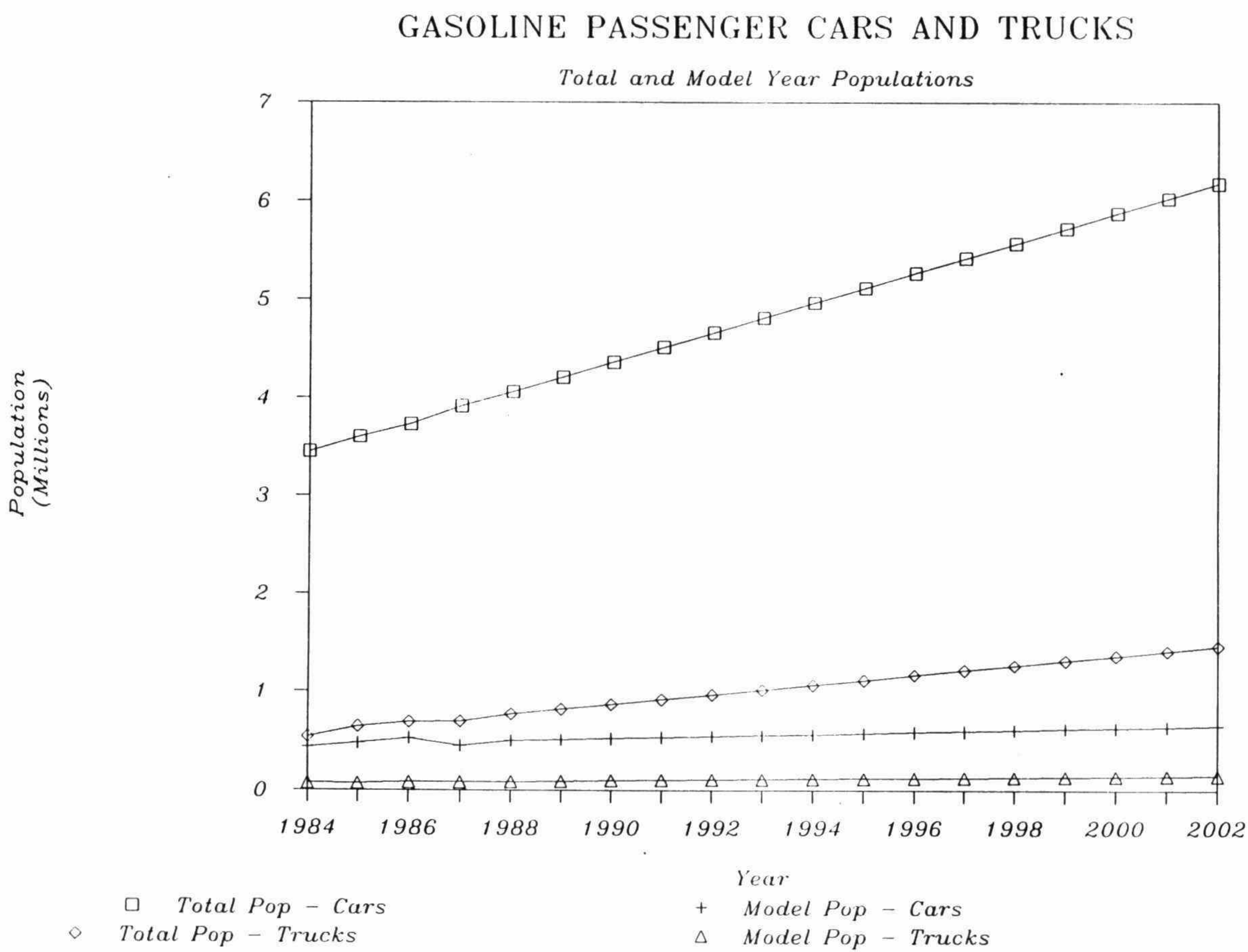
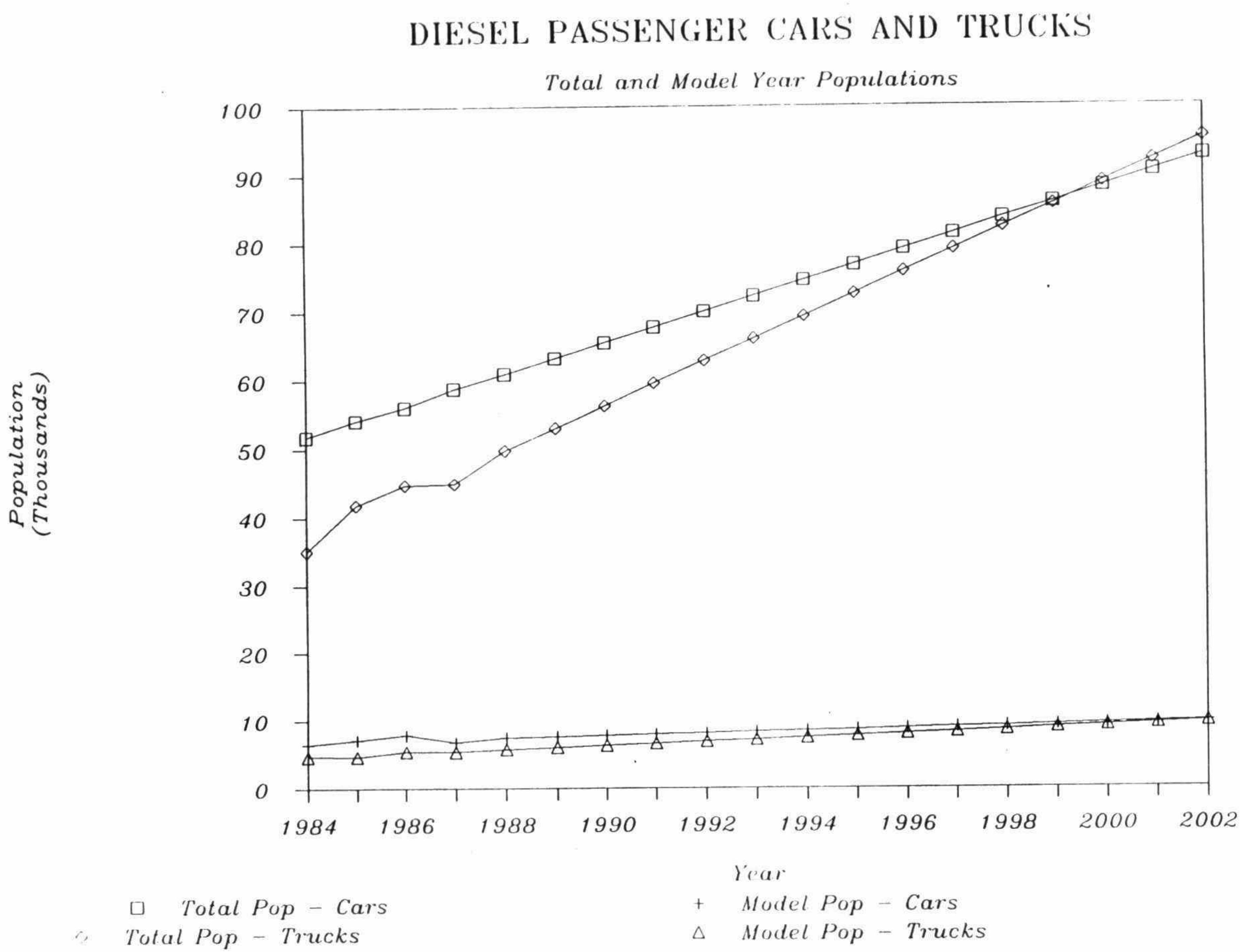

GASOLINE PASSENGER CARS AND TRUCKS
Total and Model Year Populations
Population (Millions)
7
6
5
4
3
2
1
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year
Total Pop - Cars
Total Pop - Trucks
Model Pop - Cars
Model Pop - Trucks

Figure 2.1



DIESEL PASSENGER CARS AND TRUCKS
Total and Model Year Populations
Population (Thousands)
100
90
80
70
60
50
40
30
20
10
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year
□ Total Pop - Cars
◇ Total Pop - Trucks
+ Model Pop - Cars
△ Model Pop - Trucks

Figure 2.2

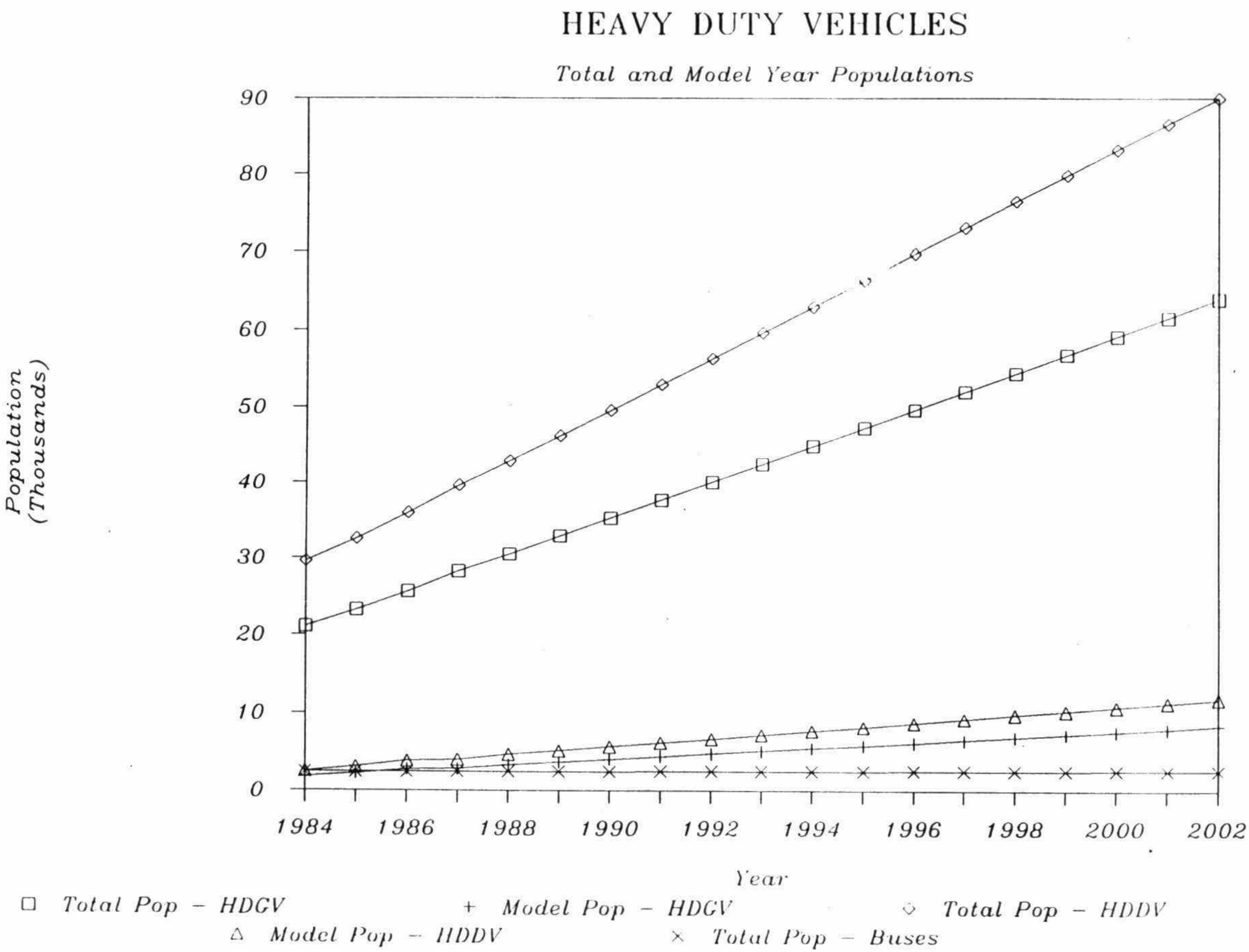

HEAVY DUTY VEHICLES
Total and Model Year Populations
Population (Thousands)
90
80
70
60
50
40
30
20
10
0
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year
Total Pop - HDGV
Model Pop - HDGV
Total Pop - HDDV
Model Pop - HDDV
Total Pop - Buses

Figure 2.3

TABLE 2.2

PROJECTED MOTOR VEHICLE POPULATIONS - Light Duty Vehicles

Model Year	Total Population	Number of Model Year Vehicles	Total Population	Number of Model Year Vehicles	Total Population	Number of Model Year Vehicles	Total Population	Number of Model Year Vehicles
	Passenger Cars - Gasoline		Light Duty Trucks - Gasoline		Passenger Cars - Diesel		Light Duty Trucks - Diesel	
1984	3,453,000	433,603	539,000	72,552	51,795	6,504	35,035	4,716
1985	3,609,000	476,189	643,000	72,107	54,135	7,143	41,795	4,687
1986	3,735,000	526,503	688,000	83,747	56,025	7,898	44,720	5,444
1987	3,917,000	453,263	691,000	83,133	58,755	6,799	44,915	5,404
1988	4,058,000 *	499,713 *	765,500 *	88,730 *	60,870 *	7,496 *	49,757 *	5,767 *
1989	4,209,800 *	510,642 *	815,600 *	93,068 *	63,147 *	7,660 *	53,014 *	6,049 *
1990	4,361,600 *	521,572 *	865,700 *	97,406 *	65,424 *	7,824 *	56,271 *	6,331 *
1991	4,513,400 *	532,501 *	915,800 *	101,744 *	67,701 *	7,988 *	59,527 *	6,613 *
1992	4,665,200 *	543,431 *	965,900 *	106,083 *	69,978 *	8,151 *	62,784 *	6,895 *
1993	4,817,000 *	554,360 *	1,016,000 *	110,421 *	72,255 *	8,315 *	66,040 *	7,177 *
1994	4,968,800 *	565,289 *	1,066,100 *	114,759 *	74,532 *	8,479 *	69,297 *	7,459 *
1995	5,120,600 *	576,219 *	1,116,200 *	119,097 *	76,809 *	8,643 *	72,553 *	7,741 *
1996	5,272,400 *	587,148 *	1,166,300 *	123,435 *	79,086 *	8,807 *	75,810 *	8,023 *
1997	5,424,200 *	598,078 *	1,216,400 *	127,773 *	81,363 *	8,971 *	79,066 *	8,305 *
1998	5,576,000 *	609,007 *	1,266,500 *	132,111 *	83,640 *	9,135 *	82,323 *	8,587 *
1999	5,727,800 *	619,936 *	1,316,600 *	136,449 *	85,917 *	9,299 *	85,579 *	8,869 *
2000	5,879,600 *	630,866 *	1,366,700 *	140,787 *	88,194 *	9,463 *	88,836 *	9,151 *
2001	6,031,400 *	641,795 *	1,416,800 *	145,126 *	90,471 *	9,627 *	92,092 *	9,433 *
2002	6,183,200 *	652,725 *	1,466,900 *	149,464 *	92,748 *	9,791 *	95,349 *	9,715 *

Note: *: projected motor vehicle population.

TABLE 2.3

PROJECTED MOTOR VEHICLE POPULATIONS - Heavy Duty Vehicles

Model Year	Total Population	Number of Model Year Vehicles	Total Population	Number of Model Year Vehicles	Total Population
	Heavy Duty Vehicles - Gasoline		Heavy Duty Vehicles - Diesel		Buses
1984	21,085	1,832	29,600	2,572	2458
1985	23,223	2,254	32,602	3,164	2472
1986	25,639	2,777	35,994	3,899	2472
1987	28,264	2,885	39,678	4,050	2500
1988	30,541 *	3,357 *	42,875 *	4,713 *	2500 *
1989	32,936 *	3,725 *	46,238 *	5,230 *	2514 *
1990	35,332 *	4,093 *	49,600 *	5,747 *	2525 *
1991	37,727 *	4,462 *	52,963 *	6,263 *	2536 *
1992	40,122 *	4,830 *	56,325 *	6,780 *	2547 *
1993	42,517 *	5,198 *	59,688 *	7,297 *	2558 *
1994	44,913 *	5,566 *	63,051 *	7,814 *	2569 *
1995	47,308 *	5,934 *	66,413 *	8,330 *	2581 *
1996	49,703 *	6,302 *	69,776 *	8,847 *	2592 *
1997	52,099 *	6,670 *	73,138 *	9,364 *	2603 *
1998	54,494 *	7,038 *	76,501 *	9,881 *	2614 *
1999	56,889 *	7,406 *	79,864 *	10,397 *	2625 *
2000	59,284 *	7,774 *	83,226 *	10,914 *	2636 *
2001	61,680 *	8,143 *	86,589 *	11,431 *	2647 *
2002	64,075 *	8,511 *	89,952 *	11,948 *	2658 *

Note: *: projected motor vehicle population.

TABLE 2.4

PROJECTED MOTOR VEHICLE POPULATIONS - Heavy Duty Gasoline Vehicles

Model Year	Total Population	Number of Model Year Vehicles	Total Population	Number of Model Year Vehicles
	Light HDGV		Medium HDGV	
1984	16,235	1,411	4,850	421
1985	17,882	1,735	5,341	518
1986	19,742	2,139	5,897	639
1987	21,763	2,221	6,501	663
1988	23,517 *	2,585 *	7,024 *	772 *
1989	25,361 *	2,869 *	7,575 *	857 *
1990	27,205 *	3,152 *	8,126 *	941 *
1991	29,050 *	3,435 *	8,677 *	1,026 *
1992	30,894 *	3,719 *	9,228 *	1,111 *
1993	32,738 *	4,002 *	9,779 *	1,195 *
1994	34,583 *	4,286 *	10,330 *	1,280 *
1995	36,427 *	4,569 *	10,881 *	1,365 *
1996	38,272 *	4,853 *	11,432 *	1,449 *
1997	40,116 *	5,136 *	11,983 *	1,534 *
1998	41,960 *	5,419 *	12,534 *	1,619 *
1999	43,805 *	5,703 *	13,085 *	1,703 *
2000	45,649 *	5,986 *	13,635 *	1,788 *
2001	47,493 *	6,270 *	14,186 *	1,873 *
2002	49,338 *	6,553 *	14,737 *	1,957 *

Note: *: projected motor vehicle population.

TABLE 2.5

PROJECTED MOTOR VEHICLE POPULATIONS - Heavy Duty Diesel Vehicles

Model Year	Total Population	Number of Model Year Vehicles	Total Population	Number of Model Year Vehicles	Total Population	Number of Model Year Vehicles
	Light HDDV		Medium HDDV		Heavy HDDV	
1984	8,880	772	7,400	643	13,320	1,157
1985	9,781	949	8,150	791	14,671	1,424
1986	10,798	1,170	8,998	975	16,197	1,755
1987	11,903	1,215	9,920	1,012	17,855	1,822
1988	12,862 *	1,414 *	10,719 *	1,178 *	19,294 *	2,121 *
1989	13,871 *	1,569 *	11,559 *	1,307 *	20,807 *	2,353 *
1990	14,880 *	1,724 *	12,400 *	1,437 *	22,320 *	2,586 *
1991	15,889 *	1,879 *	13,241 *	1,566 *	23,833 *	2,818 *
1992	16,898 *	2,034 *	14,081 *	1,695 *	25,346 *	3,051 *
1993	17,906 *	2,189 *	14,922 *	1,824 *	26,860 *	3,284 *
1994	18,915 *	2,344 *	15,763 *	1,953 *	28,373 *	3,516 *
1995	19,924 *	2,499 *	16,603 *	2,083 *	29,886 *	3,749 *
1996	20,933 *	2,654 *	17,444 *	2,212 *	31,399 *	3,981 *
1997	21,942 *	2,809 *	18,285 *	2,341 *	32,912 *	4,214 *
1998	22,950 *	2,964 *	19,125 *	2,470 *	34,425 *	4,446 *
1999	23,959 *	3,119 *	19,966 *	2,599 *	35,939 *	4,679 *
2000	24,968 *	3,274 *	20,807 *	2,729 *	37,452 *	4,911 *
2001	25,977 *	3,429 *	21,647 *	2,858 *	38,965 *	5,144 *
2002	26,985 *	3,584 *	22,488 *	2,987 *	40,478 *	5,376 *

Note: *: projected motor vehicle population.

the Ontario Ministry of the Environment [27]. This information was obtained from a sample of 295 cars tested in 1984 at the testing facility in Downsview, Ontario. All the cars were tested "in-received" condition using the owner's gasoline. The emission rates of these Ontario cars were higher than rates available from U.S. sources. This is the result of the fact that, historically, Canadian emission standards have been higher than those in the U.S.

The cars tested in the 1984 program ranged in age from new to 10 years old. Average emission rates were calculated for each age group. A straight line regression was then applied to the emission rates, so that an average deterioration rate from cars for the years 1975 to 1984 could be calculated. The average emission rate for new cars was used as the standard zero mile level emission rate. As the cars aged, the average deterioration rate was added annually to the average emission rate to obtain the age-dependent emission rate for the vehicles. The annual deterioration rate was then the increase in the pollutant emission rate per year.

Population: Two sources of vehicle populations were available: The population of gasoline-powered passenger vehicles was obtained from Statistics Canada for the four years 1984 to 1987 [7]. The model year population was obtained from the Ontario Plate/Registrant/Vehicle report of 1987 [1].

2.2.2 Light Duty Trucks (Gasoline): Calculation Of Emissions and Vehicle Populations

Emissions: This data was obtained from Tables 1.1.2A to 1.1.2B of the EPA reference [5], "Low altitude light-duty gasoline-powered vehicles'. The truck emissions estimated were for all commercial trucks that weighed less than or equal to 6,350 kg.

Population: The total and model year populations were obtained from the

commercial vehicle section of the Ontario Plate/Registrant/Vehicle report of 1984 to 1987 [1]. These trucks were mainly pick-up trucks and vans that were used for commercial purposes rather than for personal use. These populations were about 89% of the total and model year commercial vehicle populations. Non-commercial vehicles were included with the passenger vehicles in the Ontario Plate/Registrant/Vehicle report.

2.2.3 Diesel Passenger Cars and Trucks: Calculation Of Emissions and Vehicle Populations

Emissions: Annual composite fleet emission factors for light duty diesel vehicles (LDDV's) were obtained from the Mobile 3C Program [6]. Two cases were considered. The first assumed no changes in composite fleet emissions from 1987 onwards, while the second assumed a steady reduction in the fleet emissions until 1995 as estimated by the Mobile 3C program. Only NO_x and particulate emissions were considered. Other pollutants such as CO and hydrocarbons were ignored since these emissions are negligible from diesel vehicles.

Population: The total and model year populations for diesel cars were 1.5% of the passenger car populations. For diesel trucks, they were 6.5% of the light duty truck populations [20]. For the years in which there was no data, the populations were interpolated or extrapolated using a simple linear regression.

2.2.4 Motorcycles: Calculation Of Emissions And Vehicle Populations

Emissions: Emission factor data was taken from the draft data for Mobile 4. The motorcycle population was assumed to be 60% 4-stroke and 40% 2-stroke [6].

The deterioration rates were obtained from the Mobile 4 estimates in which the deterioration rates were assumed to be a fixed percentage of the zero mileage emission rates. For 1977 to 1884, the deterioration rates were 5% for carbon monoxide and 10% for hydrocarbons. For 1985 onwards, the deterioration rates were 10% for carbon monoxide and 20% for hydrocarbons. No deterioration rate for nitrogen oxides was used [6].

Population: The population data for motorcycles was obtained from Statistics Canada [7] and the Ontario Ministry of Transportation [1]. It was felt that the Statistics Canada data overestimated the motorcycle population, and that the Ministry data was more accurate. However, Ministry of Transportation data was only available for the year 1987.

To adjust the Statistics Canada data, the number of motorcycles for 1987, as supplied by the Ministry of Transportation were subtracted from the number stated by Statistics Canada for 1987. This difference was subtracted from all the Statistics Canada data and a regression done on the adjusted data.

A percent population breakdown based on the age of the vehicle was done using the 1987 data [1]. For each year, emission factors and deterioration rates were then applied according to the age of the vehicle and the percentage of the vehicle population of that age.

2.2.5 Buses: Calculation Of Emissions And Vehicle Populations

Emissions: The emission factors were obtained from Appendix N, Table N-1 [5] and were based on test results from a diesel-powered heavy duty vehicle test.

Population: The number of bus vehicle-km's travelled per year was obtained from Statistics Canada [8] for the years 1977 to 1983, the "National Transportation Agency of Canada: Transportation Report: Oct. 1985 to Dec. 1987" [9], and the "Canadian Transport Commission: Transport Review, July 1987-1988" [10].

Sample Calculations

Given the year to date data for July 1987, an estimation was made of the average monthly bus-km travelled. The total bus-km per year was then calculated by multiplying this value by 12.

For example, in 1987,

(97,519,856 bus km-travelled to July)/(7 months)*(12 months)
=1.67E08 km/year

To obtain the grams of pollutant emitted per year the above value was multiplied by the emission factor. For example,

For example, carbon monoxide in 1987,
Carbon Monoxide - 1987
Total CO emitted = # bus- km / year * EF
= (1.67E08 km/yr)(77.5 grams/mile)(0.62 mile/km)
= 8033 tonnes/year.

2.2.6 Heavy Duty Diesel Vehicles (HDDV): Calculation Of Emissions And Vehicle Populations

Emissions: Canadian emission factors for heavy diesel vehicles for NOx and particulates were obtained from the Transport Canada report [4]. The total carbon monoxide and hydrocarbon emissions are negligible from diesel engines, consequently they were ignored in the final analysis. Only particulate and Nox emissions are significant.

Some of the emission rates provided in the report were given as an average over the life of the vehicle, while others were given as a zero mile emission factor and a deterioration rate for every 16,000 km driven [4]. Since a yearly deterioration was needed, the average annual distance travelled was divided by 16000 km; this was multiplied by the deterioration factor giving a deterioration rate for each year of driving.

Population: The total and model year population of all heavy duty vehicles

was calculated from the 1984 to 1987 Ontario Ministry of Transportation Data on Commercial Vehicles [1]. The percentage that was diesel, 58.4%, was obtained from the Transport Canada analysis [4].

The percent population breakdown by age of the vehicle was based on 1987 data for active commercial vehicles as found in the Ontario Ministry of Transportation Plate/Registrant/Vehicle populations.

The average annual mileage travelled by the light, medium, and heavy duty diesel vehicles and the percentage of the heavy duty diesel truck population classified as light, medium, and heavy were obtained from the Transport Canada analysis [4]. A composite milage was obtained for all HDDV for each year by multiplying the annual mileage for each weight class by the percentage of the class and summing. The results were then converted from miles to kilometers.

2.2.7 Heavy Duty Gasoline Vehicles (HDGV): Calculation Of Emissions And Vehicle Populations

Emissions: Emissions data for heavy duty gasoline vehicles were obtained from the Transport Canada report [4]. The emission factors provided in the report were given as a zero mile emission levels and deterioration rates for every 16000 km driven. These were converted to yearly deterioration rates similarly to heavy duty diesel vehicles.

Population: The total and model year populations of heavy duty gasoline vehicles were obtained from the Ontario Ministry of Transportation data on commercial vehicles [1]. The fraction of commercial vehicles which was gasoline was 0.416. The percent population breakdown by age was obtained from the 1987 Ontario Ministry of Transportation data [1] for active commercial vehicles as for HDDV's. This was used to calculate yearly mileage composites for all HDGV's, as described in the section on HDDV's.

The heavy duty gasoline vehicles were divided into light and medium heavy duty weight classes.

3.0 OTHER MOBILE POLLUTION SOURCES

3.1 Summary Of The Emissions From Other Sources

In Ontario, motor vehicles, light and heavy duty, are not the only mobile source of the pollutants NO_x, CO, hydrocarbons, particulates, SO_x, and aldehydes. As part of this study, other miscellaneous mobile sources were identified, and their contribution to Ontario's total pollution burden was estimated. These other mobile pollution sources that were identified are listed in Table 3.1.

For each source, the emission levels in tonnes per year of particulates, NO_x, SO_x, aldehydes, hydrocarbons, and CO were estimated for the years from 1976 to 1988. Projected emission levels for the year 2002 were also calculated. The assumptions used in estimating the source populations and their emission rates are presented in Section 3.2.

For each mobile source, the contribution of each source to the total annual emissions levels over the fourteen years has been analyzed. The contribution of each source of CO, hydrocarbons, NO_x, particulates, SO_x, and aldehydes are depicted in the pie charts, Figures 3.1 to 3.6, for the years 1987 and 2002. The pollutant emissions used in these figures are given in Tables 3.2 to 3.13.

In 1987, the new motor vehicle emission standards were implemented which affected all 1988 and future model year vehicles. By the year 2002, all 1987 model year and older passenger cars and light duty trucks should no longer be on the road. All the vehicles on the road will then meet the 1987 emission standards. Consequently, the contribution of these vehicles to the total pollution emission levels may be altered by this time.

For the pollutants CO, hydrocarbons, and NO_x, light duty vehicles were the major single mobile source of these pollutants in 1988. Particulates were produced mainly by heavy diesel vehicles. Aldehydes and SO_x emission levels were not determined for motor vehicles since emission rates were not

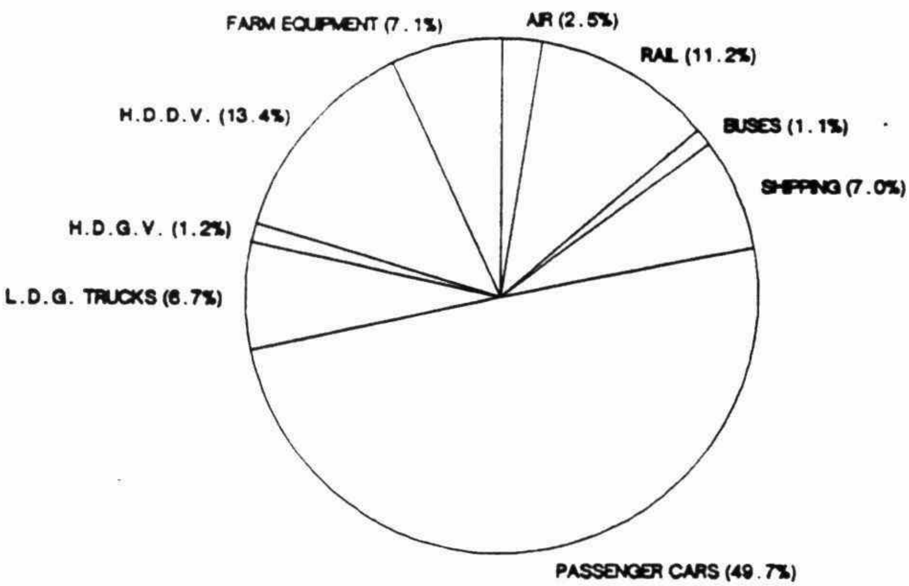
TABLE 3.1.

MISCELLANEOUS MOBILE POLLUTION SOURCES

Other Transportation Sources:	Aircraft Shipping Railway
Household Facilities:	Lawnmowers Snowblowers Snowmobiles Recreational Boats
Farm Equipment:	Tractors Combines Swathers Balers Harvesters

NITROGEN OXIDE EMISSIONS FOR 1987

Total : 277,722 tonnes per year



NITROGEN OXIDE EMISSIONS FOR 2002

Total : 240,922 tonnes per year

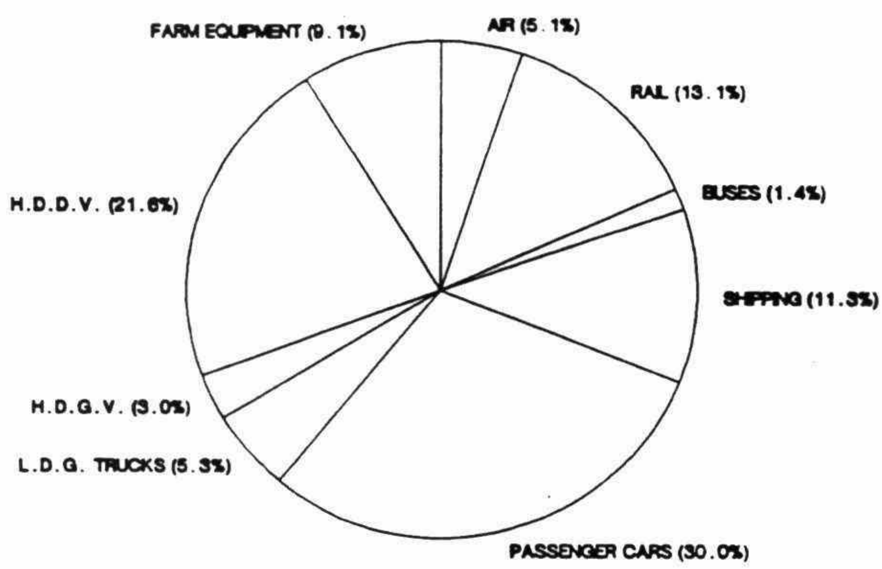
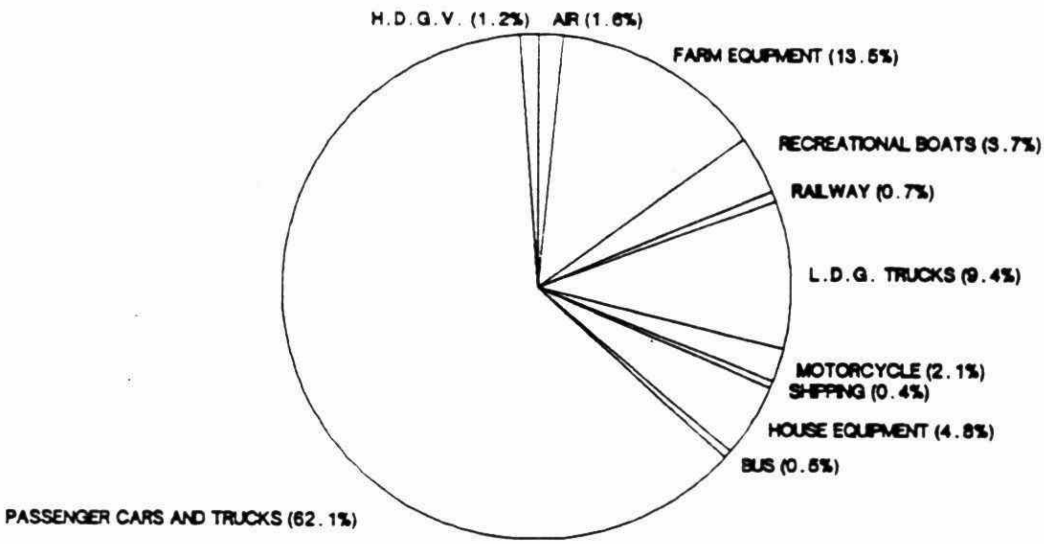


Figure 3.1

CARBON MONOXIDE EMISSIONS FOR 1987

Total : 1,715,368 tonnes per year



CARBON MONOXIDE EMISSIONS FOR 2002

Total : 1,758,257 tonnes per year

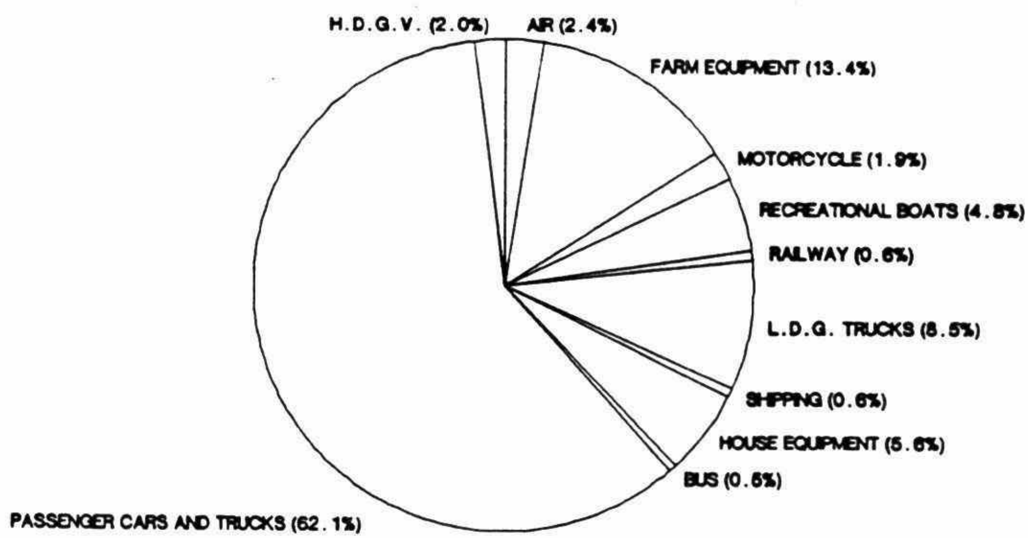
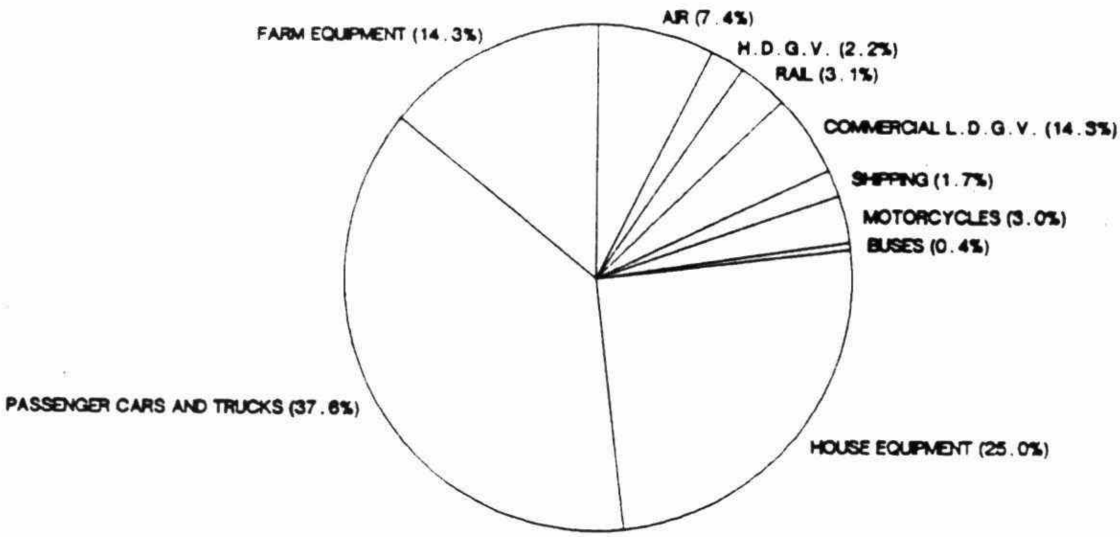


Figure 3.2

HYDROCARBON EMISSIONS FOR 1987.

Total : 239,621 tonnes per year



HYDROCARBON EMISSIONS FOR 2002.

Total : 265,760 tonnes per year

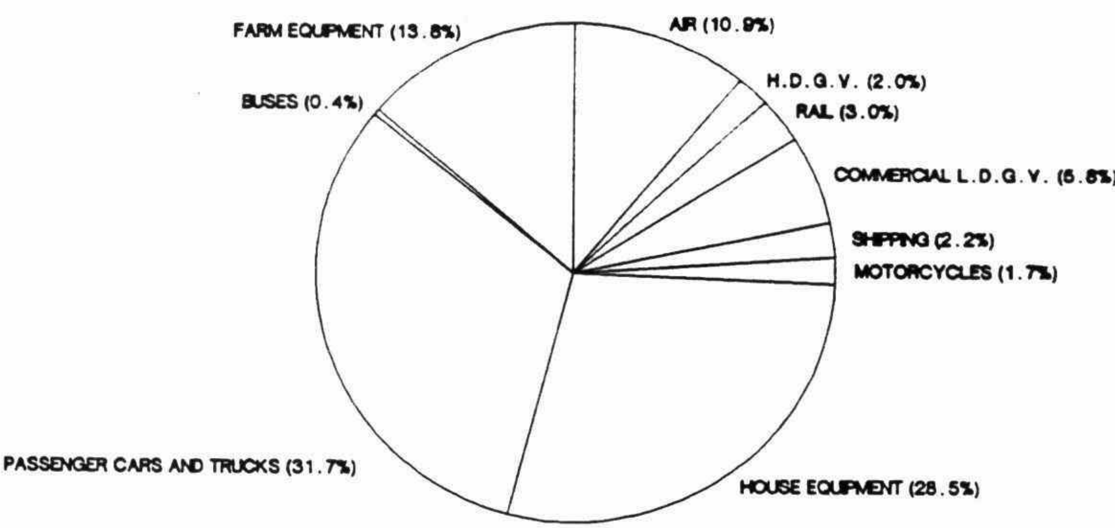
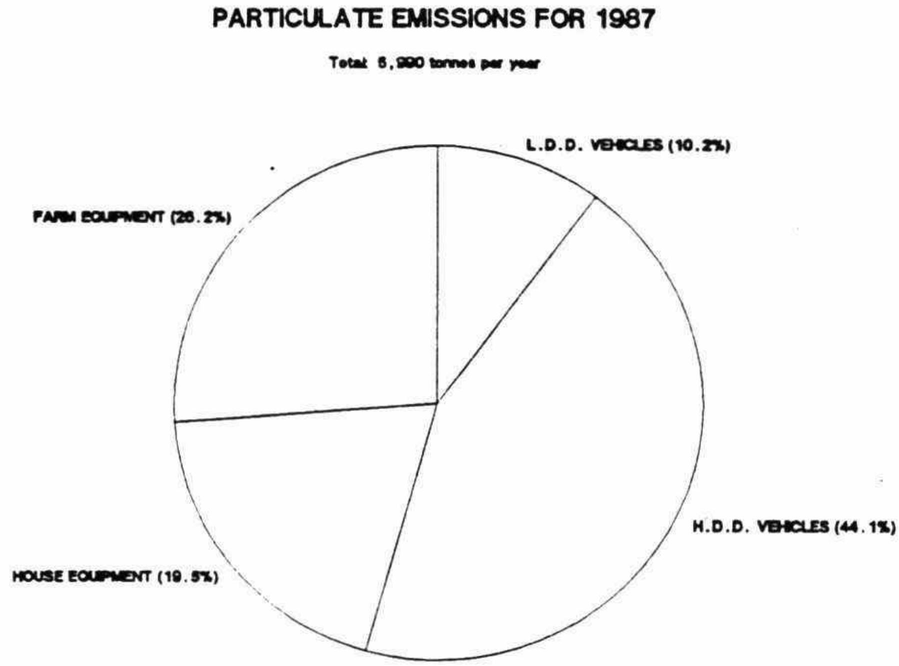


Figure 3.3


PARTICULATE EMISSIONS FOR 1987
Total: 5,990 tonnes per year
L.D.D. VEHICLES (10.2%)
FARM EQUIPMENT (26.2%)
H.D.D. VEHICLES (44.1%)
HOUSE EQUIPMENT (19.5%)

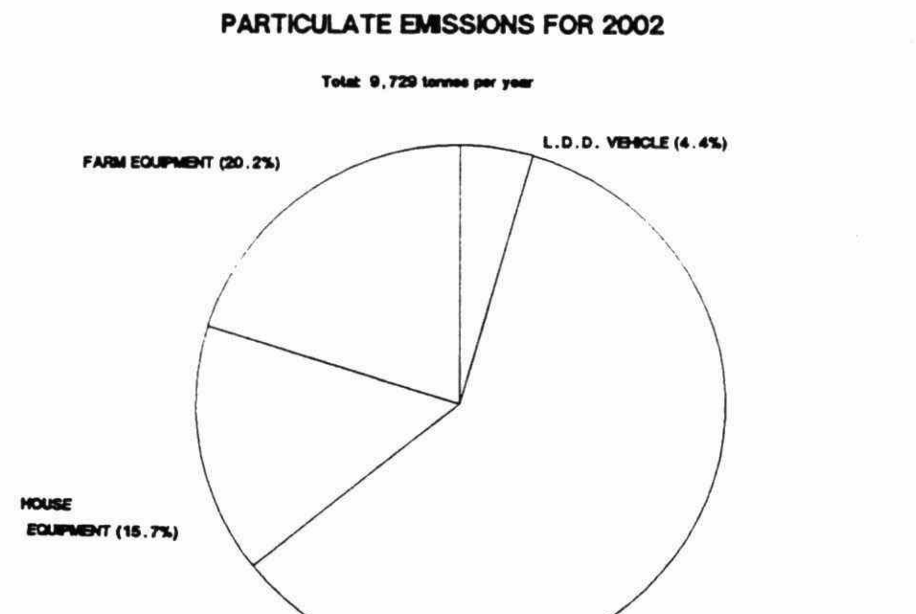
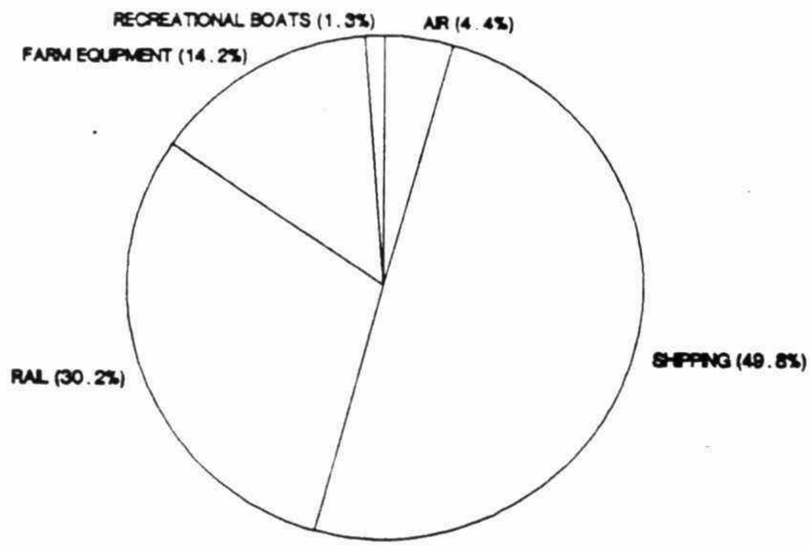

PARTICULATE EMISSIONS FOR 2002
Total: 9,729 tonnes per year
L.D.D. VEHICLE (4.4%)
FARM EQUIPMENT (20.2%)
HOUSE
EQUIPMENT (15.7%)
H.D.D. VEHICLES (59.8%)

Figure 3.4

SULPHUR OXIDE EMISSIONS FOR 1987.

Total : 15,697 tonnes per year



SULPHUR OXIDE EMISSIONS FOR 2002.

Total : 18,441 tonnes per year

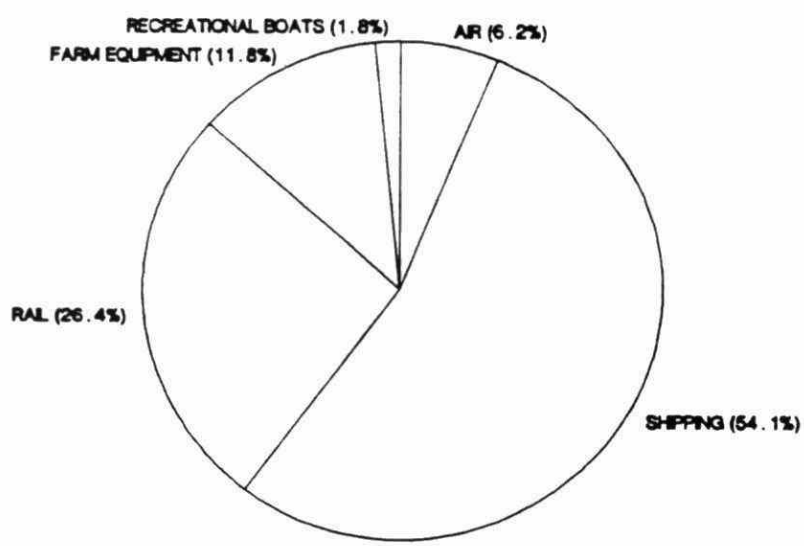
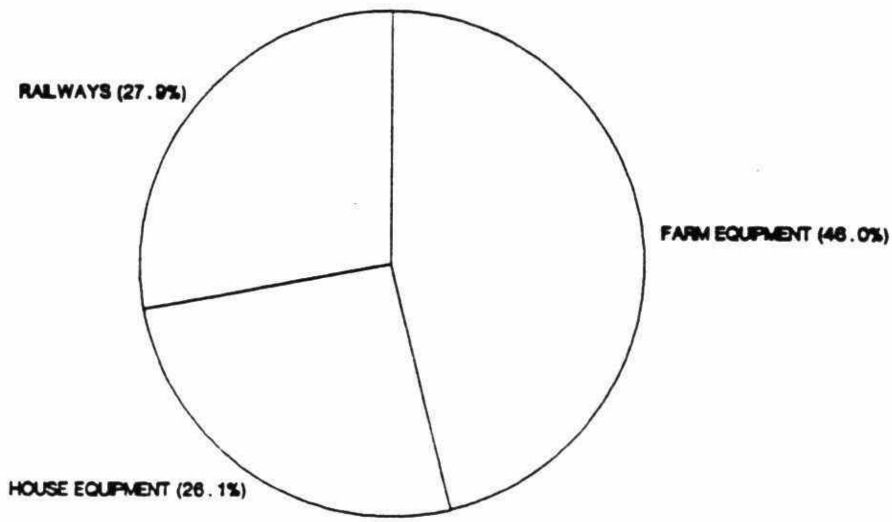


Figure 3.5

ALDEHYDE EMISSIONS FOR 1987.

Total : 1,652 tonnes per year



ALDEHYDE EMISSIONS FOR 2002.

Total : 1,731 tonnes per year

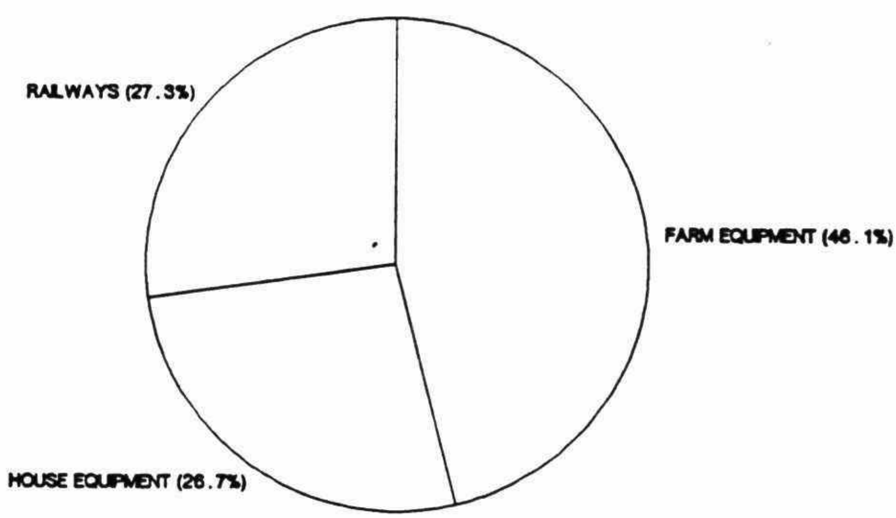


Figure 3.6

TABLE 3.2

TOTAL ANNUAL NITROGEN OXIDE EMISSIONS FOR ONTARIO FROM MOBILE SOURCES
(tonnes per year)

YEAR	AIR	SHIPPING	RAILWAYS	PASSENGER CARS GASOLINE	PASSENGER CARS DIESEL	LIGHT-DUTY TRUCKS GASOLINE	LIGHT-DUTY TRUCKS DIESEL	MOTORCYLES	HDGV	HDDV
1976	3,200 *	13,745 *	29,512 *	70,738	590	4,369	251	491	205	2,328
1977	3,541 *	17,021	29,559 *	76,698	638	5,701	335	491	478	5,430
1978	3,882 *	14,223	29,607 *	82,628	683	7,033	419	589	750	8,532
1979	4,223 *	15,225 *	29,654 *	88,577	724	8,365	499	666	1,023	11,634
1980	4,564 *	14,388	29,702 *	94,525	765	9,697	578	775	1,296	14,735
1981	4,905 *	12,378	29,749 *	100,474	801	11,029	643	873	1,569	17,837
1982	5,245 *	15,863	30,126	106,422	826	12,361	670	939	1,842	20,939
1983	5,586 *	19,272	29,968	112,371	871	13,694	444	1,017	2,115	24,041
1984	5,927 *	19,348	29,891 *	117,615	912	14,332	726	1,070	2,402	27,305
1985	6,250	18,185 *	28,937	125,276	929	17,097	852	1,154	2,645	30,074
1986	6,645	18,678 *	29,849	130,314	899	18,294	907	1,135	2,920	33,203
1987	6,932	19,171 *	30,721	135,764	890	18,373	881	1,128	3,219	36,601
1988	7,291 *	19,664 *	30,081 *	127,007	881	17,841	975	1,162	3,479	39,550
2002	12,065 *	26,570 *	30,746 *	70,231	1,178	12,473	1869	1,158	7,041	50,637

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	BALERS	SWATHERS	HARVESTERS	TOTAL NOX:
1976	2,903 *	240 *	443 *	117 *	26 *	13,476	1,238	1,232	744	995	146,842
1977	2,920 *	234 *	503 *	120 *	29 *	14,234 *	1,212 *	1,218 *	660 *	911 *	161,933
1978	2,937 *	229 *	564 *	123 *	32 *	14,335 *	1,209 *	1,217 *	671 *	922 *	170,582
1979	2,954 *	223 *	624 *	126 *	34 *	14,435 *	1,205 *	1,216 *	682 *	934 *	183,023
1980	2,972 *	216	757	130	38	14,536 *	1,202 *	1,215 *	693 *	945 *	193,729
1981	2,989 *	211 *	745 *	132 *	39 *	14,302	1,222	1,245	812	1,030	202,986
1982	3,006 *	205 *	704	135 *	42 *	14,738 *	1,195 *	1,213 *	716 *	968 *	218,157
1983	3,023 *	200 *	865 *	139 *	45 *	14,839 *	1,192 *	1,212 *	727 *	980 *	232,598
1984	3,040 *	194 *	926 *	140	45	14,940 *	1,189 *	1,211 *	738 *	991 *	242,941
1985	3,063	191	986 *	145 *	50 *	15,040 *	1,185 *	1,210 *	749 *	1,002 *	255,020
1986	3,063	182 *	1,047 *	148 *	53 *	14,475	1,154	1,174	656	914	265,709
1987	3,098	174	1,136	152	57	15,242 *	1,179 *	1,207 *	771 *	1,025 *	277,722
1988	3,109 *	171 *	1,167 *	154 *	58 *	15,343 *	1,175 *	1,206 *	782 *	1,037 *	272,134
2002	3,350 *	90 *	2,013 *	197 *	95 *	16,755 *	1,128 *	1,192 *	937 *	1,198 *	240,922

Note: *: value was estimated by linear regression.

TABLE 3.3

TOTAL ANNUAL NITROGEN OXIDE EMISSIONS FOR ONTARIO FROM MOBILE SOURCES
(percent of total)

YEAR	AIR	SHIPPING	RAILWAYS	PASSENGER CARS GASOLINE	PASSENGER CARS DIESEL	LIGHT-DUTY TRUCKS GASOLINE	LIGHT-DUTY TRUCKS DIESEL	MOTORCYLES	HDGV	HDDV
1976	2.2 *	9.4 *	20.1 *	48.2	0.4	3.0	0.2	0.3	0.1	1.6
1977	2.2 *	10.5	18.3 *	47.4	0.4	4.3	0.2	0.3	0.3	3.4
1978	2.3 *	8.3	17.4 *	48.4	0.4	4.9	0.2	0.3	0.4	5.0
1979	2.3 *	8.3 *	16.2 *	48.4	0.4	4.6	0.3	0.4	0.6	6.4
1980	2.4 *	7.4	15.3 *	48.8	0.4	5.0	0.3	0.4	0.7	7.6
1981	2.4 *	6.1	14.7 *	49.5	0.4	5.4	0.3	0.4	0.8	8.8
1982	2.4 *	7.3	13.8	48.8	0.4	5.7	0.3	0.4	0.8	9.6
1983	2.4 *	8.3	12.9	48.3	0.4	5.9	0.2	0.4	0.9	10.3
1984	2.4 *	8.0	12.3 *	48.4	0.4	5.9	0.3	0.4	1.0	11.2
1985	2.5	7.1 *	11.3	49.1	0.4	6.7	0.3	0.5	1.0	11.8
1986	2.5	7.0 *	11.2	49.0	0.3	6.9	0.3	0.4	1.1	12.5
1987	2.5	6.9 *	11.1	48.9	0.3	6.6	0.3	0.4	1.2	13.2
1988	2.7 *	7.2 *	11.1 *	46.7	0.3	6.6	0.4	0.4	1.3	14.5
2002	5.0 *	11.0 *	12.8 *	29.2	0.5	5.2	0.8	0.5	2.9	21.0

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	BALERS	SWATHERS	HARVESTERS
1976	2.0 *	0.2 *	0.3 *	0.1 *	0.0 *	9.2	0.8	0.8	0.5	0.7
1977	1.8 *	0.1 *	0.3 *	0.1 *	0.0 *	8.8 *	0.7 *	0.8 *	0.4 *	0.6 *
1978	1.7 *	0.1 *	0.3 *	0.1 *	0.0 *	8.4 *	0.7 *	0.7 *	0.4 *	0.5 *
1979	1.6 *	0.1 *	0.3 *	0.1 *	0.0 *	7.9 *	0.7 *	0.7 *	0.4 *	0.5 *
1980	1.5 *	0.1	0.4	0.1	0.0	7.5 *	0.6 *	0.6 *	0.4 *	0.5 *
1981	1.5 *	0.1 *	0.4 *	0.1 *	0.0 *	7.0	0.6	0.6	0.4	0.5
1982	1.4 *	0.1 *	0.3	0.1 *	0.0 *	6.8 *	0.5 *	0.6 *	0.3 *	0.4 *
1983	1.3 *	0.1 *	0.4 *	0.1 *	0.0 *	6.4 *	0.5 *	0.5 *	0.3 *	0.4 *
1984	1.3 *	0.1 *	0.4 *	0.1	0.0	6.1 *	0.5 *	0.5 *	0.3 *	0.4 *
1985	1.2	0.1	0.4 *	0.1 *	0.0 *	5.9 *	0.5 *	0.5 *	0.3 *	0.4 *
1986	1.2	0.1 *	0.4 *	0.1 *	0.0 *	5.4	0.4	0.4	0.2	0.3
1987	1.1	0.1	0.4	0.1	0.0	5.5 *	0.4 *	0.4 *	0.3 *	0.4 *
1988	1.1 *	0.1 *	0.4 *	0.1 *	0.0 *	5.6 *	0.4 *	0.4 *	0.3 *	0.4 *
2002	1.4 *	0.0 *	0.8 *	0.1 *	0.0 *	7.0 *	0.5 *	0.5 *	0.4 *	0.5 *

Note: *: value was estimated by linear regression.

TABLE 3.4

TOTAL ANNUAL ONTARIO CARBON MONOXIDE EMISSIONS FROM MOBILE SOURCES
(tonnes per year)

YEAR	AIR	SHIPPING	RAILWAY	PASSENGER CAR GASOLINE	PASSENGER CAR DIESEL	LIGHT-DUTY TRUCKS GASOLINE	LIGHT-DUTY TRUCKS DIESEL	MOTORCYCLES	HDGV	HDDV
1976	14,257 *	5,323 *	10,626 *	554,005	CO	47,143	CO	61,948	1,311	CO
1977	15,383 *	6,584	10,657 *	600,597	EMISSIONS	58,159	EMISSIONS	61,948	3,059	EMISSIONS
1978	16,509 *	5,594	10,688 *	647,189	NEGLIGIBLE	69,175	NEGLIGIBLE	59,904	4,806	NEGLIGIBLE
1979	17,634 *	5,960 *	10,720 *	693,782		80,191		58,230	6,554	
1980	18,760 *	5,714	10,751 *	740,374		91,207		55,065	8,301	
1981	19,885 *	4,823	10,782 *	786,966		102,223		52,007	10,048	
1982	21,011 *	6,257	10,955	833,558		113,240		47,855	11,796	
1983	22,137 *	7,601	10,897	880,150		118,517		45,708	13,543	
1984	23,262 *	7,701	10,875 *	921,227		141,385		43,042	15,382	
1985	24,388	7,236 *	10,523	981,226		151,279		42,733	16,942	
1986	25,501	7,448 *	10,854	1,020,688		151,939		39,260	18,704	
1987	26,602	7,661 *	11,171	1,063,380		161,422		36,535	20,619	
1988	27,750 *	7,873 *	11,070 *	1,058,240		163,806		36,397	22,280	
2002	43,488 *	10,849 *	11,000 *	1,058,240		125,595		34,502	35,571	

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	SWATHERS	BALERS	HARVESTERS	TOTAL CO:
1976	8,216 *	23,494 *	59,295 *	36,137 *	8,125 *	140,383	22,316	15,453	51,174	451	1,059,657
1977	8,255 *	22,927 *	62,467 *	37,096 *	8,943 *	140,349 *	22,318 *	12,266 *	51,512 *	459 *	1,122,977
1978	8,293 *	22,360 *	65,639 *	38,054 *	9,761 *	141,246 *	22,166 *	12,126 *	51,271 *	455 *	1,185,237
1979	8,332 *	21,794 *	68,810 *	39,013 *	10,579 *	142,144 *	22,014 *	11,987 *	51,030 *	452 *	1,249,224
1980	8,370 *	21,132	55,237	40,180	11,757	143,041 *	21,862 *	11,847 *	50,789 *	448 *	1,294,835
1981	8,409 *	20,660 *	75,154 *	40,930 *	12,214 *	142,077	22,017	16,860	51,705	467	1,377,230
1982	8,447 *	20,093 *	61,211	41,889 *	13,032 *	144,836 *	21,558 *	11,568 *	50,307 *	441 *	1,418,054
1983	8,486 *	19,527 *	81,498 *	42,848 *	13,850 *	145,734 *	21,406 *	11,428 *	50,066 *	437 *	1,493,832
1984	8,524 *	18,960 *	84,670 *	43,320	13,828 *	146,632 *	21,254 *	11,289 *	49,825 *	433 *	1,561,608
1985	8,572	18,725	87,842 *	44,765 *	15,486	147,529 *	21,102 *	11,149 *	49,584 *	430 *	1,639,511
1986	8,572	17,827 *	91,013 *	45,724 *	16,304 *	149,358	20,796	13,627	48,765	367	1,686,747
1987	8,669	17,023	67,208	46,960	17,602	149,324 *	20,798 *	10,870 *	49,102 *	422 *	1,715,368
1988	8,669 *	16,693 *	97,357 *	47,641 *	17,939 *	150,222 *	20,646 *	10,730 *	48,862 *	419 *	1,746,595
2002	9,218 *	8,760 *	91,942 *	61,062 *	29,389 *	162,787 *	18,518 *	11,479 *	45,488 *	367 *	1,758,257

Note: *: value was estimated by linear regression.

TABLE 3.5

TOTAL ANNUAL ONTARIO CARBON MONOXIDE EMISSIONS FROM MOBILE SOURCES
(percent of total)

YEAR	AIR	SHIPPING	RAILWAY	PASSENGER CAR GASOLINE	PASSENGER CAR DIESEL	LIGHT-DUTY TRUCKS GASOLINE	LIGHT-DUTY TRUCKS DIESEL	MOTORCYCLES	HDGV	HDDV
1976	1.3 *	0.5 *	1.0 *	52.3	CO	4.4	CO	5.8	0.1	CO
1977	1.4 *	0.6	0.9 *	53.5	EMISSIONS	5.2	EMISSIONS	5.5	0.3	EMISSIONS
1978	1.4 *	0.5	0.9 *	54.6	NEGLIGIBLE	5.8	NEGLIGIBLE	5.1	0.4	NEGLIGIBLE
1979	1.4 *	0.5 *	0.9 *	55.5		6.4		4.7	0.5	
1980	1.4 *	0.4	0.8 *	57.2		7.0		4.3	0.6	
1981	1.4 *	0.4	0.8 *	57.1		7.4		3.8	0.7	
1982	1.5 *	0.4	0.8	58.8		8.0		3.4	0.8	
1983	1.5 *	0.5	0.7	58.9		7.9		3.1	0.9	
1984	1.5 *	0.5	0.7 *	59.0		9.1		2.8	1.0	
1985	1.5 *	0.4 *	0.6	59.8		9.2		2.6	1.0	
1986	1.5	0.4 *	0.6	60.5		9.0		2.3	1.1	
1987	1.6	0.4 *	0.7	62.0		9.4		2.1	1.2	
1988	1.6 *	0.5 *	0.6 *	60.6		9.4		2.1	1.3	
2002	2.5 *	0.6 *	0.6 *	60.2		7.1		2.0	2.0	

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	SWATHERS	BALERS	HARVESTERS
1976	0.8 *	2.2 *	5.6 *	3.4 *	0.8 *	13.2	2.1	1.5	4.8	0.0
1977	0.7 *	2.0 *	5.6 *	3.3 *	0.8 *	12.5 *	2.0 *	1.1 *	4.6 *	0.0 *
1978	0.7 *	1.9 *	5.5 *	3.2 *	0.8 *	11.9 *	1.9 *	1.0 *	4.3 *	0.0 *
1979	0.7 *	1.7 *	5.5 *	3.1 *	0.8 *	11.4 *	1.8 *	1.0 *	4.1 *	0.0 *
1980	0.6 *	1.6	4.3	3.1	0.9	11.0 *	1.7 *	0.9 *	3.9 *	0.0 *
1981	0.6 *	1.5 *	5.5 *	3.0 *	0.9 *	10.3	1.6	1.2	3.8	0.0
1982	0.6 *	1.4 *	4.3	3.0 *	0.9 *	10.2 *	1.5 *	0.8 *	3.5 *	0.0 *
1983	0.6 *	1.3 *	5.5 *	2.9 *	0.9 *	9.8 *	1.4 *	0.8 *	3.4 *	0.0 *
1984	0.5 *	1.2 *	5.4 *	2.8	0.9 *	9.4 *	1.4 *	0.7 *	3.2 *	0.0 *
1985	0.5	1.1	5.4 *	2.7 *	0.9	9.0 *	1.3 *	0.7 *	3.0 *	0.0 *
1986	0.5	1.1 *	5.4 *	2.7 *	1.0 *	8.9	1.2	0.8	2.9	0.0
1987	0.5	1.0	3.9	2.7	1.0	8.7 *	1.2 *	0.6 *	2.9 *	0.0 *
1988	0.5 *	1.0 *	5.6 *	2.7 *	1.0 *	8.6 *	1.2 *	0.6 *	2.8 *	0.0 *
2002	0.5 *	0.5 *	5.2 *	3.5 *	1.7 *	9.3 *	1.1 *	0.7 *	2.6 *	0.0 *

Note: *: value was estimated by linear regression.

TABLE 3.6

TOTAL ANNUAL ONTARIO HYDROCARBON EMISSIONS FROM MOBILE SOURCES
(tonnes per year)

YEAR	AIR	SHIPPING	RAILWAY	PASSENGER CAR GASOLINE	PASSENGER CAR DIESEL	LIGHT-DUTY TRUCKS GASOLINE	LIGHT-DUTY TRUCKS DIESEL	MOTORCYCLES	HDGV	HDDV
1976	9,507 *	2,866 *	7,305 *	46,901	HC	2,991	HC	15,824	331	HC
1977	10,257 *	2,980	7,327 *	50,845	EMISSIONS	3,904	EMISSIONS	15,824	773	EMISSIONS
1978	11,008 *	3,095	7,348 *	54,789	NEGLIGIBLE	4,816	NEGLIGIBLE	14,379	1,215	NEGLIGIBLE
1979	11,758 *	3,209 *	7,370 *	58,734		5,728		13,284	1,656	
1980	12,509 *	3,324	7,391 *	62,678		6,640		12,214	2,098	
1981	13,260 *	3,438	7,413 *	66,622		7,552		11,243	2,540	
1982	14,010 *	3,553	7,434	70,567		8,465		10,132	2,981	
1983	14,761 *	3,667	7,455	74,511		9,377		9,589	3,423	
1984	15,511 *	3,782	7,477 *	77,988		9,814		8,959	3,888	
1985	16,262	3,896 *	7,498	83,068		11,707		8,723	4,282	
1986	17,012	4,011 *	7,520	86,409		12,527		7,822	4,728	
1987	17,763	4,125 *	7,541	90,023		12,581		7,118	5,212	
1988	18,513 *	4,239 *	7,562 *	86,627		12,988		6,765	5,631	
2002	29,021 *	5,842 *	7,862 *	84,298		15,312		4,601	5,440	

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	SWATHERS	BALERS	HARVESTERS	TOTAL HC:
1976	984 *	15,129 *	16,734 *	16,027 *	3,604 *	28,710	1,020	627	2,077	183	170,819
1977	989 *	14,764 *	17,241 *	16,452 *	3,966 *	28,703 *	1,020 *	651 *	2,090 *	186 *	177,973
1978	994 *	14,399 *	17,749 *	16,877 *	4,329 *	28,886 *	1,013 *	644 *	2,081 *	185 *	183,806
1979	998 *	14,034 *	18,256 *	17,302 *	4,692 *	29,070 *	1,006 *	636 *	2,071 *	183 *	189,988
1980	1,003 *	13,608	18,321	17,820	5,214	29,254 *	999 *	629 *	2,061 *	182 *	195,944
1981	1,007 *	13,304 *	19,271 *	18,153 *	5,417 *	29,056	1,006	684	2,098	189	202,254
1982	1,012 *	12,939 *	18,321	18,578 *	5,780 *	29,621 *	985 *	614 *	2,042 *	179 *	207,211
1983	1,017 *	12,574 *	20,285 *	19,003 *	6,143 *	29,804 *	978 *	607 *	2,032 *	177 *	215,404
1984	1,021 *	12,209 *	20,793 *	19,212	6,133	29,988 *	971 *	599 *	2,022 *	176 *	220,543
1985	1,026	12,058	21,300 *	19,853 *	6,868 *	30,171 *	964 *	592 *	2,012 *	174 *	230,456
1986	1,031	11,480 *	21,807 *	20,279 *	7,231 *	30,545	950	553	1,979	168	236,050
1987	1,035	10,962	20,398	20,827	7,806	30,538 *	950 *	577 *	1,993 *	171 *	239,621
1988	1,040 *	10,750 *	22,822 *	21,129 *	7,956 *	30,722 *	943 *	570 *	1,983 *	170 *	240,411
2002	1,104 *	5,641 *	29,925 *	27,081 *	13,034 *	33,292 *	846 *	466 *	1,846 *	149 *	265,760

Note: *: value was estimated by linear regression.

TABLE 3.7

TOTAL ANNUAL ONTARIO HYDROCARBON EMISSIONS FROM MOBILE SOURCES
(percent of total)

YEAR	AIR	SHIPPING	RAILWAY	PASSENGER CAR GASOLINE	PASSENGER CAR DIESEL	LIGHT-DUTY TRUCKS GASOLINE	LIGHT-DUTY TRUCKS DIESEL	MOTORCYCLES	HDGV	HDDV
1976	5.6 *	1.7 *	4.3 *	27.5	HC	1.8	HC	9.3	0.2	HC
1977	5.8 *	1.7	4.1 *	28.6	EMISSIONS	2.2	EMISSIONS	8.9	0.4	EMISSIONS
1978	6.0 *	1.7	4.0 *	29.8	NEGLIGIBLE	2.6	NEGLIGIBLE	7.8	0.7	NEGLIGIBLE
1979	6.2 *	1.7 *	3.9 *	30.9		3.0		7.0	0.9	
1980	6.4 *	1.7	3.8 *	32.0		3.4		6.2	1.1	
1981	6.6 *	1.7	3.7 *	32.9		3.7		5.6	1.3	
1982	6.8 *	1.7	3.6	34.1		4.1		4.9	1.4	
1983	6.9 *	1.7	3.5	34.6		4.4		4.5	1.6	
1984	7.0 *	1.7	3.4 *	35.4		4.4		4.1	1.8	
1985	7.1	1.7 *	3.3	36.0		5.1		3.8	1.9	
1986	7.2	1.7 *	3.2	36.6		5.3		3.3	2.0	
1987	7.4	1.7 *	3.1	37.6		5.3		3.0	2.2	
1988	7.7 *	1.8 *	3.1 *	36.0		5.4		2.8	2.3	
2002	10.9 *	2.2 *	3.0 *	31.7		5.8		1.7	2.0	

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	SWATHERS	BALERS	HARVESTERS
1976	0.6 *	8.9 *	9.8 *	9.4 *	2.1 *	16.8	0.6	0.4	1.2	0.1
1977	0.6 *	8.3 *	9.7 *	9.2 *	2.2 *	16.1 *	0.6 *	0.4 *	1.2 *	0.1 *
1978	0.5 *	7.8 *	9.7 *	9.2 *	2.4 *	15.7 *	0.6 *	0.4 *	1.1 *	0.1 *
1979	0.5 *	7.4 *	9.6 *	9.1 *	2.5 *	15.3 *	0.5 *	0.3 *	1.1 *	0.1 *
1980	0.5 *	6.9	9.3	9.1	2.7	14.9 *	0.5 *	0.3 *	1.1 *	0.1 *
1981	0.5 *	6.6 *	9.5 *	9.0 *	2.7 *	14.4	0.5	0.3	1.0	0.1
1982	0.5 *	6.2 *	8.8	9.0 *	2.8 *	14.3 *	0.5 *	0.3 *	1.0 *	0.1 *
1983	0.5 *	5.8 *	9.4 *	8.8 *	2.9 *	13.8 *	0.5 *	0.3 *	0.9 *	0.1 *
1984	0.5 *	5.5 *	9.4 *	8.7	2.8	13.6 *	0.4 *	0.3 *	0.9 *	0.1 *
1985	0.4	5.2	9.2 *	8.6 *	3.0 *	13.1 *	0.4 *	0.3 *	0.9 *	0.1 *
1986	0.4	4.9 *	9.2 *	8.6 *	3.1 *	12.9	0.4	0.2	0.8	0.1
1987	0.4	4.6	8.5	8.7	3.3	12.7 *	0.4 *	0.2 *	0.8 *	0.1 *
1988	0.4 *	4.5 *	9.5 *	8.8 *	3.3 *	12.8 *	0.4 *	0.2 *	0.8 *	0.1 *
2002	0.4 *	2.1 *	11.3 *	10.2 *	4.9 *	12.5 *	0.3 *	0.2 *	0.7 *	0.1 *

Note: *: value was estimated by linear regression.

TABLE 3.8

TOTAL ANNUAL ONTARIO PARTICULATE EMISSIONS FROM MOBILE SOURCES
(tonnes per year)

YEAR	AIR	SHIPPING	RAILWAY	PASSENGER CAR GASOLINE	LIGHT-DUTY DIESEL VEHICLE	LIGHT-DUTY TRUCKS GASOLINE	MOTORCYCLES	HDGV	HDDV
1976	PARTICULATE EMISSION			PARTICULATE	308	PARTICULATE	PARTICULATE	PARTICULATE	191
1977	RATES NOT AVAILABLE			EMISSIONS	349	EMISSIONS	EMISSION	EMISSIONS	445
1978				NEGLIGIBLE	388	NEGLIGIBLE	RATES NOT	NEGLIGIBLE	699
1979					427		AVAILABLE		953
1980					466				1,207
1981					505				1,461
1982					543				1,715
1983					582				1,969
1984					609				2,236
1985					673				2,463
1986					707				2,719
1987					728				2,997
1988					664				3,239
2002					431				5,816

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	SWATHERS	BALERS	HARVESTERS	TOTAL PARTICULATES:
1976	PARTICULATE	668 *	PARTICULATE	509 *	114 *	1,414	157	124	93	18	3,597
1977	EMISSION	652 *	EMISSION	522 *	126 *	1,414 *	157 *	128 *	94 *	19 *	3,906
1978	RATES NOT	636 *	RATES NOT	535 *	137 *	1,423 *	156 *	127 *	93 *	19 *	4,214
1979	AVAILABLE	620 *	AVAILABLE	549 *	149 *	1,432 *	155 *	125 *	93 *	18 *	4,522
1980		601		565	165	1,441 *	154 *	124 *	92 *	18 *	4,835
1981		588 *		576 *	172 *	1,431	155	135	94	19	5,136
1982		572 *		589 *	183 *	1,459 *	152 *	121 *	92 *	18 *	5,444
1983		556 *		603 *	195 *	1,468 *	151 *	120 *	91 *	18 *	5,752
1984		539 *		610	195	1,477 *	150 *	118 *	91 *	18 *	6,042
1985		533		630 *	218 *	1,486 *	149 *	117 *	90 *	18 *	6,376
1986		507 *		643 *	229 *	1,505	147	109	89	17	6,672
1987		484		661	248	1,504 *	147 *	114 *	89 *	17 *	6,990
1988		475 *		670 *	252 *	1,514 *	146 *	112 *	89 *	17 *	7,178
2002		249 *		859 *	414 *	1,640 *	131 *	92 *	83 *	15 *	9,729

Note: *: value was estimated by linear regression.

TABLE 3.9

TOTAL ANNUAL ONTARIO PARTICULATE EMISSIONS FROM MOBILE SOURCES
(percent of total)

YEAR	AIR	SHIPPING	RAILWAY	PASSENGER CAR GASOLINE	LIGHT-DUTY DIESEL VEHICLE	LIGHT-DUTY TRUCKS GASOLINE	MOTORCYCLES	HDGV	HDDV
1976	PARTICULATE EMISSION			PARTICULATE	8.6	PARTICULATE	PARTICULATE	PARTICULATE	5.3
1977	RATES NOT AVAILABLE			EMISSIONS	8.9	EMISSIONS	EMISSION	EMISSIONS	11.4
1978				NEGLIGIBLE	9.2	NEGLIGIBLE	RATES NOT	NEGLIGIBLE	16.6
1979					9.4		AVAILABLE		21.1
1980					9.6				25.0
1981					9.8				28.4
1982					10.0				31.5
1983					10.1				34.2
1984					10.1				37.0
1985					10.6				38.6
1986					10.6				40.7
1987					10.4				42.9
1988					9.3				45.1
2002					4.4				59.8

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	SWATHERS	BALERS	HARVESTERS
1976	PARTICULATE	18.6 *	PARTICULATE	14.1 *	3.2 *	39.3	4.4	3.4	2.6	0.5
1977	EMISSION	16.7 *	EMISSION	13.4 *	3.2 *	36.2 *	4.0 *	3.3 *	2.4 *	0.5 *
1978	RATES NOT	15.1 *	RATES NOT	12.7 *	3.3 *	33.8 *	3.7 *	3.0 *	2.2 *	0.4 *
1979	AVAILABLE	13.7 *	AVAILABLE	12.1 *	3.3 *	31.7 *	3.4 *	2.8 *	2.1 *	0.4 *
1980		12.4		11.7	3.4	29.8 *	3.2 *	2.6 *	1.9 *	0.4 *
1981		11.4 *		11.2 *	3.3 *	27.9	3.0	2.6	1.8	0.4
1982		10.5 *		10.8 *	3.4 *	26.8 *	2.8 *	2.2 *	1.7 *	0.3 *
1983		9.7 *		10.5 *	3.4 *	25.5 *	2.6 *	2.1 *	1.6 *	0.3 *
1984		8.9 *		10.1	3.2	24.4 *	2.5 *	2.0 *	1.5 *	0.3 *
1985		8.4		9.9 *	3.4 *	23.3 *	2.3 *	1.8 *	1.4 *	0.3 *
1986		7.6 *		9.6 *	3.4 *	22.6	2.2	1.6	1.3	0.3
1987		6.9		9.5	3.5	21.5 *	2.1 *	1.6 *	1.3 *	0.2 *
1988		6.6 *		9.3 *	3.5 *	21.1 *	2.0 *	1.6 *	1.2 *	0.2 *
2002		2.6 *		8.8 *	4.3 *	16.9 *	1.3 *	0.9 *	0.9 *	0.2 *

Note: *: value was estimated by linear regression.

TABLE 3.10

TOTAL ANNUAL ONTARIO SULPHUR OXIDE EMISSIONS FROM MOBILE SOURCES
(tonnes per year)

YEAR	AIR	SHIPPING	RAILWAYS	PASSENGER CAR GASOLINE	PASSENGER CAR DIESEL	LIGHT-DUTY TRUCKS GASOLINE	LIGHT-DUTY TRUCKS DIESEL	MOTORCYCLES	HDGV	HDDV
1976	373 *	6,247 *	4,516 *	NO SOX	NO SOX	NO SOX	NO SOX	NO SOX	NO SOX	NO SOX
1977	403 *	1,621	4,529 *	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS
1978	432 *	1,377	4,543 *	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED
1979	462 *	6,677 *	4,556 *							
1980	491 *	1,407	4,569 *							
1981	521 *	1,187	4,582 *							
1982	550 *	1,540	4,656							
1983	579 *	1,871	4,631							
1984	609 *	1,896	4,622 *							
1985	638	7,537 *	4,472							
1986	668	7,680 *	4,613							
1987	697	7,824 *	4,748							
1988	727 *	7,967 *	4,675 *							
2002	1,139 *	9,973 *	4,860 *							

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	BALERS	SWATHERS	HARVESTERS	TOTAL SOX:
1976	NO SOX	NO SOX	121 *	NO SOX	NO SOX	966	105	74	77	1,029	13,508
1977	EMISSIONS	EMISSIONS	128 *	EMISSIONS	EMISSIONS	966 *	105 *	75 *	80 *	1,046 *	8,952
1978	CALCULATED	CALCULATED	135 *	CALCULATED	CALCULATED	972 *	105 *	75 *	79 *	1,038 *	8,754
1979			142 *			978 *	104 *	74 *	78 *	1,029 *	14,100
1980			151			984 *	103 *	74 *	77 *	1,021 *	8,877
1981			155 *			977	104	75	84	1,064	8,750
1982			159			996 *	102 *	73 *	75 *	1,004 *	9,155
1983			169 *			1,003 *	101 *	73 *	74 *	996 *	9,498
1984			176 *			1,009 *	100 *	72 *	73 *	987 *	9,545
1985			183 *			1,015 *	100 *	72 *	73 *	979 *	15,069
1986			190 *			1,028	98	71	68	945	15,361
1987			198			1,027 *	98 *	71 *	71 *	962 *	15,697
1988			204 *			1,033 *	98 *	71 *	70 *	954 *	15,799
2002			302 *			1,120 *	88 *	66 *	57 *	837 *	18,441

Note: *: value was estimated by linear regression.

TABLE 3.11

TOTAL ANNUAL ONTARIO SULPHUR OXIDE EMISSIONS FROM MOBILE SOURCES
(percent of total)

YEAR	AIR	SHIPPING	RAILWAYS	PASSENGER CAR GASOLINE	PASSENGER CAR DIESEL	LIGHT-DUTY TRUCKS GASOLINE	LIGHT-DUTY TRUCKS DIESEL	MOTORCYCLES	HDGV	HDDV
1976	2.8 *	46.2 *	33.4 *	NO SOX	NO SOX	NO SOX	NO SOX	NO SOX	NO SOX	NO SOX
1977	4.5 *	18.1	50.6 *	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS
1978	4.9 *	15.7	51.9 *	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED
1979	3.3 *	47.4 *	32.3 *							
1980	5.5 *	15.8	51.5 *							
1981	5.9 *	13.6	52.4 *							
1982	6.0 *	16.8	50.9							
1983	6.1 *	19.7	48.8							
1984	6.4 *	19.9	48.4 *							
1985	4.2	50.0 *	29.7							
1986	4.3	50.0 *	30.0							
1987	4.4	49.8 *	30.2							
1988	4.6 *	50.4 *	29.6 *							
2002	6.2 *	54.1 *	26.4 *							

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	BALERS	SWATHERS	HARVESTERS
1976	NO SOX	NO SOX	0.9 *	NO SOX	NO SOX	7.1	0.8	0.6	0.6	7.6
1977	EMISSIONS	EMISSIONS	1.4 *	EMISSIONS	EMISSIONS	10.8 *	1.2 *	0.8 *	0.9 *	11.7 *
1978	CALCULATED	CALCULATED	1.5 *	CALCULATED	CALCULATED	11.1 *	1.2 *	0.9 *	0.9 *	11.9 *
1979			1.0 *			6.9 *	0.7 *	0.5 *	0.6 *	7.3 *
1980			1.7			11.1 *	1.2 *	0.8 *	0.9 *	11.5 *
1981			1.8 *			11.2	1.2	0.9	1.0	12.2
1982			1.7			10.9 *	1.1 *	0.8 *	0.8 *	11.0 *
1983			1.8 *			10.6 *	1.1 *	0.8 *	0.8 *	10.5 *
1984			1.8 *			10.6 *	1.1 *	0.8 *	0.8 *	10.3 *
1985			1.2 *			6.7 *	0.7 *	0.5 *	0.5 *	6.5 *
1986			1.2 *			6.7	0.6	0.5	0.4	6.2
1987			1.3			6.5 *	0.6 *	0.5 *	0.5 *	6.1 *
1988			1.3 *			6.5 *	0.6 *	0.4 *	0.4 *	6.0 *
2002			1.6 *			6.1 *	0.5 *	0.4 *	0.3 *	4.5 *

Note: *: value was estimated by linear regression.

TABLE 3.12

TOTAL ANNUAL ONTARIO ALDEHYDE EMISSIONS FROM MOBILE SOURCES
(tonnes per year)

YEAR	AIR	SHIPPING	RAILWAYS	PASSENGER CAR GASOLINE	PASSENGER CAR DIESEL	LIGHT-DUTY TRUCKS GASOLINE	LIGHT-DUTY TRUCKS DIESEL	MOTORCYCLES	HDGV	HDDV
1976	NO	NO	438 *	NO	NO	NO	NO	NO	NO	NO
1977	ALDEHYDE	ALDEHYDE	440 *	ALDEHYDE	ALDEHYDE	ALDEHYDE	ALDEHYDE	ALDEHYDE	ALDEHYDE	ALDEHYDE
1978	EMISSIONS	EMISSIONS	441 *	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS
1979	CALCULATED	CALCULATED	442 *	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED
1980			443 *							
1981			445 *							
1982			452							
1983			450							
1984			449 *							
1985			434							
1986			448							
1987			461							
1988			457 *							
2002			472 *							

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWNMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	BALERS	SWATHERS	HARVESTERS	TOTAL ALDEHYDES:
1976	NO	221 *	NO	151 *	34 *	570	48	56	26	34	1,579
1977	ALDEHYDE	216 *	ALDEHYDE	155 *	37 *	570 *	48 *	56 *	27 *	35 *	1,584
1978	EMISSIONS	210 *	EMISSIONS	160 *	41 *	573 *	48 *	56 *	26 *	35 *	1,590
1979	CALCULATED	205 *	CALCULATED	164 *	44 *	577 *	48 *	56 *	26 *	34 *	1,596
1980		199		168	49	581 *	47 *	55 *	26 *	34 *	1,603
1981		194 *		172 *	51 *	577	48	56	28	35	1,606
1982		189 *		176 *	55 *	588 *	47 *	55 *	25 *	33 *	1,619
1983		184 *		180 *	58 *	592 *	46 *	55 *	25 *	33 *	1,622
1984		178 *		182	58	595 *	46 *	54 *	24 *	33 *	1,620
1985		176		188 *	65 *	599 *	46 *	54 *	24 *	33 *	1,618
1986		168 *		192 *	68 *	606	45	53	23	31	1,634
1987		160		197	74	606 *	45 *	54 *	24 *	32 *	1,652
1988		157 *		200 *	75 *	610 *	45 *	53 *	23 *	32 *	1,652
2002		82 *		256 *	123 *	661 *	40 *	50 *	19 *	28 *	1,731

Note: *: value was estimated by linear regression.

TABLE 3.13

TOTAL ANNUAL ONTARIO ALDEHYDE EMISSIONS FROM MOBILE SOURCES
(percent of total)

YEAR	AIR	SHIPPING	RAILWAYS	PASSENGER CAR GASOLINE	PASSENGER CAR DIESEL	LIGHT-DUTY TRUCKS GASOLINE	LIGHT-DUTY TRUCKS DIESEL	MOTORCYCLES	HDGV	HDDV
1976	NO	NO	27.8 *	NO	NO	NO	NO	NO	NO	NO
1977	ALDEHYDE	ALDEHYDE	27.8 *	ALDEHYDE	ALDEHYDE	ALDEHYDE	ALDEHYDE	ALDEHYDE	ALDEHYDE	ALDEHYDE
1978	EMISSIONS	EMISSIONS	27.7 *	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS	EMISSIONS
1979	CALCULATED	CALCULATED	27.7 *	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED	CALCULATED
1980			27.7 *							
1981			27.7 *							
1982			27.9							
1983			27.7							
1984			27.7 *							
1985			26.8							
1986			27.4							
1987			27.9							
1988			27.6 *							
2002			27.3 *							

YEAR	BUSES	SNOWMOBILES	RECREATIONAL BOATS	LAWMMOWERS	SNOWBLOWERS	TRACTORS	COMBINES	BALERS	SWATHERS	HARVESTERS
1976	NO	14.0 *	NO	9.6 *	2.2 *	36.1	3.1	3.5	1.6	2.2
1977	ALDEHYDE	13.6 *	ALDEHYDE	9.8 *	2.4 *	36.0 *	3.1 *	3.6 *	1.7 *	2.2 *
1978	EMISSIONS	13.2 *	EMISSIONS	10.0 *	2.6 *	36.1 *	3.0 *	3.5 *	1.7 *	2.2 *
1979	CALCULATED	12.8 *	CALCULATED	10.2 *	2.8 *	36.2 *	3.0 *	3.5 *	1.6 *	2.1 *
1980		12.4		10.5	3.1	36.2 *	3.0 *	3.5 *	1.6 *	2.1 *
1981		12.1 *		10.7 *	3.2 *	35.9	3.0	3.5	1.7	2.2
1982		11.7 *		10.8 *	3.4 *	36.3 *	2.9 *	3.4 *	1.5 *	2.1 *
1983		11.3 *		11.1 *	3.6 *	36.5 *	2.9 *	3.4 *	1.5 *	2.0 *
1984		11.0 *		11.2	3.6	36.8 *	2.8 *	3.4 *	1.5 *	2.0 *
1985		10.9		11.6 *	4.0 *	37.0 *	2.8 *	3.3 *	1.5 *	2.0 *
1986		10.3 *		11.7 *	4.2 *	37.1	2.8	3.3	1.4	1.9
1987		9.7		11.9	4.5	36.7 *	2.7 *	3.2 *	1.4 *	1.9 *
1988		9.5 *		12.1 *	4.6 *	36.9 *	2.7 *	3.2 *	1.4 *	1.9 *
2002		4.8 *		14.8 *	7.1 *	38.2 *	2.3 *	2.9 *	1.1 *	1.6 *

Note: *: value was estimated by linear regression.

available. Farm equipment was the most important source of aldehyde air emissions. Other transportation sources, air, shipping, and railways, were the major source for aldehydes (28%) and SO_x (85%).

By the year 2002, the total annual emission levels of hydrocarbons, particulates, SO_x, and aldehydes will have increased from the 1988 levels. This is a result of the increased populations of the sources. Any gain due to more stringent emission standards for motor vehicles will be offset for these three pollutants. Between 2002 and 1988, the percentage increase in the annual emissions estimated for hydrocarbons, SO_x, particulates, and aldehydes are 11%, 17%, 36% and 5% respectively. Only for NO_x (-11%) is the projected emission level expected to decrease. CO will remain relatively unchanged (+0.1%).

3.2 Miscellaneous Mobile Pollution Sources

3.2.1 Sources Of Information

The purpose of this section is to identify the pollution emissions from miscellaneous mobile pollution sources excluding automobiles (e.g. lawnmowers, snowmobiles, airplanes, and buses.).

Statistics Canada was used as a major source of information for the population of the different pollutant emitters. Values were obtained in the years from 1977 to 1987. These were used to estimate by linear regression the number of emitters in the year 2002. The United States Environmental Protection Agency reference "Compilation of Air Pollutant Emission Factors, Volume II", was used to estimate the mass of pollutants emitted each year (i.e. sulphur oxides, carbon monoxide and particulates) [5].

3.2.2 Method Of Calculation

To calculate the amount of pollutant per year, two numbers were needed:

1) the number of vehicles or units of equipment being used for a particular year, and

2) an emission factor- the amount of a particular pollutant emitted per vehicle or per unit of equipment,

or,

1) the number of vehicle-km's travelled per year, and

2) the total grams of pollutant emitted per vehicle-km.

In some cases, the emission factor was based on the horsepower-hour or how many hours the vehicle or unit of equipment was used per year. In many instances, there would be a very general number for the total number vehicles or vehicle-km, while the emission factor would be quite vehicle specific. For example, there was a very general value for the total airplane-km flown, but the corresponding emission factor was very specific to engine size. In such cases, the total emissions would be impossible to calculate, so a "worst-case" estimation was made. Below, for each of the miscellaneous mobile pollution sources, an explanation of the graphs and tables presented in the report is given, and sample calculations are provided.

3.2.3 Aviation: Calculation Of Emissions And Vehicle Populations

Emissions: The emissions data was obtained from the EPA manual, Table II-1-9. "Emissions factors per aircraft per landing/take-off (LTO) cycle - civil aircraft" [5]. These values were based on "Table II-1-3 and Table II-1-5". Table II-1-3 was "Typical Duration for Civil Landing/Take-off Cycles at Large Congested Metropolitan Airports". The values in this table were based on "worst case" assumptions for the time airplanes spend in busy, congested airports within 3000 feet of the ground. Table II-1-5 provided the engine power settings for typical Environmental Protection Agency Landing-TakeOff

(LTO) commercial cycles. The power setting is the percent thrust or horsepower for a particular class of aircraft.

The aircrafts were categorized into four major classes by percentage of LTO cycles. These classes were:

- jets (28%),
- turboprops (21%),
- piston aircraft (47.5%) of the total LTO's, and
- helicopters (3.6%).

These numbers were obtained for the year 1985 (11); the source assumed that these percentage breakdowns would remain unchanged. The "worst case" emission rate for each pollutant was chosen from among the rates for individual aircrafts. (Concordes were not included).

Population: Overall commercial air movement has experienced a steady increase in hours flown from 1960 to 1980. In the early 1980's, a recession caused a steady decline in air movement, while data from 1986 to 1988 showed a steady increase. The data for 1986 to 1988 was used for the linear regression. Using the pre-1986 data would have given an inaccurate prediction of the future aircraft movements. The values that were used were the total amount of LTO's per year for 3 major airports in Ontario: Lester B. Pearson International, Ottawa International and London Airport. These airports are considered the busiest in Ontario and probably emit the most pollution per LTO, since larger planes are more frequent at these airports [12].

Sample Calculation

Carbon Monoxide (1988):
Total CO emitted per year

$= (\text{\# LTO's per year} * EF)_i$

$= 726.0$ tonnes/year

where i = jets, turboprops, piston aircraft, helicopters
EF = emission factor

3.2.4 Railways: Calculation Of Emissions And Vehicle Populations

Emission: The emission factors used were collected from Table II-2-1, "Average Locomotive Emission Factors based on Nationwide Statistics" [5]. The results were obtained from a report by Hare, C.T. et al. organized by locomotive engine category in the United States. This particulate emission data was based on highway diesel data since no actual locomotive particulate data was available. The sulphur oxide emission factor was based on fuel with 0.4 % sulphur.

Population: The calculations were based on the locomotive-kilometre travelled per year and emission factors. The locomotive-kilometre travelled per year were obtained from May 1982 to May 1988. Since the emission factor used units of kg/1000L of fuel, a value for the average fuel consumption of a locomotive had to be found. An estimation was made using the freight-car kilometers travelled for the month of March 1988, and the conversion factor "one gallon of fuel= 290 ton*mile" [13]. Calculating fuel consumption for a freight-car gave a "worst-case" gas consumption rate for locomotives.

The numbers that were found were for all of Canada, so an estimation was made as to what percentage Ontario's emissions were of the total Canadian emissions. In telephone conversations with contacts from VIA Railways and Canadian National Railways, it was estimated that between 20% and 40% of the railway-traffic was within Ontario [14]. The percentage that was used in the calculations was then 30%.

Sample Calculation

For March 1988, the all-freight tonne-kilometers were 22,986,067 and the total freight-car kilometers were 682,941,511. The fuel consumption was then

Fuel Use = (22,986,067 tonne-km)(0.6214 mile/km)(1 L/0.26417 gal)
*(1 gal/290 ton-mile)/682,941,511 km
= 0.3003 L/km.

The locomotive-kilometre travelled per year was estimated from year-to-date data from various months. The monthly average was then multiplied by 12 for the locomotive-kilometers travelled per year.

For example,
March 1988:

year-to-date	= 1,920,327,698 km for 3 months
monthly	= 1 920 327 698 km / 3 months
	= 6.40E08 km / month
average yearly	= 6.40E08 * 12 km / year
	= 7.68E09 km travelled for 1988.

Carbon Monoxide (1988):
CO = (# kilometers per year)(EF)(Fuel Use)(30 %)
= 7.68E09 * 16 kg/1000L *0.3003 L/kilometre * 0.30
= 1.107E04 tonnes per year.

3.2.5 Farm Equipment: Calculation Of Emissions And Vehicle Populations

Emissions: Emissions data was obtained from the EPA manual [5] which was based on a report by Hare and Springer. Emissions ratings were obtained for 1987 only and are assumed constant throughout the lifetime of the equipment. It should be noted that sulphur oxides were not measured but were calculated from the fuel sulphur content.

The data from [5] were divided into Tractors and Non-Tractor Farm Machinery which were further subdivided into Diesel and Gas categories. The percentage of farm equipment which used diesel and gas was given so that the

emission factor ratings could be adjusted accordingly. For example, 30% of tractors used diesel while the other 70% used gasoline. All balers used gas, while all forage crop harvesters used diesel. Swathers were not subdivided into fuel categories so "worst case" figures were used, where "worst case" represented the highest emission rate for each pollutant. Pull-type combines were 100% gasoline, while self-propelled combines were 50% diesel and 50% gas. The percentage of combines that were self-propelled has grown from 50% in 1971 to almost 80% in 1986 indicating a rise in the amount of diesel fuel used. The emission factors were adjusted using 40% diesel and 60% gasoline to be consistent with future trends. Emission ratings for Tractors and Combines were increased by 10% to account for any errors in this estimation.

Population: The total population of Tractors, Combines, Swathers, Balers and Forage Crop Harvesters was taken directly from Statistics Canada Agriculture Surveys [15]. These data are compiled every 5 years and are available from 1961 for most types of equipment. It should be noted that the population of all types of Farm Equipment except Tractors showed a decrease from 1981 to 1986 that is not accounted for in the linear regression and extrapolation to 2002. As well, the 1961 population of Balers was ignored in the regression analysis as it did not appear to be consistent with recent trends. The population of Balers from 1966 onwards showed a slight decrease.

The amount of time that the equipment was used was estimated to be 300 hrs/year. This assumed heavy use for 2.5 weeks of the year during harvest time.

Sample Calculations

Emission ratings for both Tractor and Combines were calculated from the data. The example below calculates Carbon Monoxide emissions for Tractors which were 70% gas and 30% diesel.

$$CO\ EF = (CO\ EF_{gas} * 0.7) + (CO\ EF_{diesel} * 0.3)$$
$$= (3380\ g/hour * 0.7) + (161\ g/hour * 0.3)$$
$$= 2414\ g/hour$$
Increasing by 10% = 2414 g/hour * 1.1
=2660 g/hour.

The amount of time the equipment was used in a year was calculated as follows.

Use = (16 hrs/day)(7 days/week)(2.5 weeks/year)
= 280 hrs/year = 300 hrs/year.

The total CO emissions for the year were then calculated using 1986 data for Carbon Monoxide emissions from Tractors.

Carbon Monoxide:
Total Emissions = Total Tractors * EF * use
= 187165 * 2260 g/hour * 300 hrs/year
= 1.49E+11 g/year

3.2.6 Vessels: Calculation Of Emissions And Vehicle Populations

Emissions: Inboard powered vessels as defined by the Environmental Protection Agency were classified on the basis of use [5]. The three classes were commercial, pleasure and military. The commercial vessel population and usage data were divided into Great Lakes, river, and coastal vessels. All the commercial vessels have similar characteristics such as size, weight, speed, commodities transported, engine design (external and internal combustion), fuel used and distance travelled. Great Lakes and river emissions data was used in the compilation of emission data for commercial vessels.

Population: Statistics Canada's Annual Water Transportation Catalogue, 54-205, classifies their vessels by For-Hire Carriers (Class 1, 2 and 3),

Private Carriers and Government Carriers [16]. These classes are then divided into Domestic, Atlantic, Pacific, Inland, Arctic, Mackenzie River and International.

The Inland class data were used in the compilation of the air emissions for vessels for Ontario for all types of vessels.

Sample Calculation

Carbon Monoxide (1984):

CO = fuel use * EF emission factor

= 5.92E+08 * 13 kg/1000L

= 7.70E+03 tonnes/year

3.2.7 **Recreational Boats - Outboard Motors: Calculation Of Emissions and Vehicle Populations**

Emissions: Emissions data was obtained from the Emissions Factor reference, Section II-4 [5]. The data were based on tests of four outboard motors ranging from 4 to 65 hp. A composite of the results was made based on a United States breakdown of outboards by horsepower (II-4-1). The average power produced was quoted from the same source as 9.1 hp. It should be noted that emissions from outboard motors are difficult to calculate as most have underwater exhaust.

Population: The total number of households with outboard motor boats for a given year was taken from Statistics Canada data [17]. These figures were adjusted to obtain total outboard motor boat population according to data supplied by the Allied Boating Association of Canada [18]. The Allied Boating Association information is based on a 1980 Survey by the Ministry of Natural Resources Ontario, which they have updated to 1987. They estimate 2.3 million recreational boats in Canada; of these, 39% are Ontario boats and 45% of those were outboards. There were about 403,000 outboard motor boats in Ontario in 1987. This was 1.3 times the number of houses that have

outboards as quoted by Statistics Canada. This factor was applied to all Statistics Canada data, ensuring a "worst case" figure for total emissions.

Total hours of use per year were also calculated from information supplied by the Allied Boating Association of Canada [18]. Using the same percentages as above, (39% Ontario, 45% outboards), it was determined that there were 19,305,000 outings/year for Ontario outboards. The average length of the outing was estimated to be 1.5 hrs. The total time of the outings was divided by the Ontario boat population to obtain the average use per year of 70 hrs. This corresponds to an industry estimate of 60-70 hrs/year.

Sample Calculation

The calculation for total number of outboards in Ontario in 1987 according to the Allied Boating Association is shown below:

Total Outboards Ontario = Total Boats Canada * Percent Ontario * Percent Outboard
= 2.3E+06 *.39 *.45
= 403000

The number of households with outboard motor boats in Ontario in 1987 according to Statistics Canada [17] was 307,000. A factor was then applied to all Statistics Canada data to account for houses with more than one boat; this factor was calculated as follows:

Adjustment Factor = Total Outboards / Households with Outboards
= 403000 / 307000
= 1.3

Three steps were used to calculate the total use per year. The first was to calculate the percentage of total Canadian outings which applied to Ontario outboards.

Ontario Outboard Outings = Canadian Outings * Percent Ontario *
Percent Outboard
= 110E+06 outings/year * .39 * .45
= 19,305,000 outings/year

The second step was to convert the number of outings per year to hours used in a year.

Total Boats Hours Used = Outings/Year * Hours/Outing
= 19305000 outings/year * 1.5 hrs/outing
= 28957500 hrs/year

Dividing the total hours of use per year for all Ontario outboards by the total Ontario outboard population gave the average hours of use per year.

Use = Use for all boats / Total Ontario Outboard Population
= 28957500 hrs/year / 403000
= 72 hrs/year

Total emissions per year can now be calculated. The example below uses 1987 Ontario data for Carbon Monoxide. The total number of boats was first calculated by applying the adjustment factor to Statistics Canada Data.

Total Outboards = Total Households with Outboards * AF
= 403000 * 1.3
= 523900

Total Emissions = Total Outb. * EF * Ave. hp (hp) * Use
= 523900 * 250 g/hphr * 9.1 hp * 72 hrs/year
= 85,815 tonnes/year

3.2.8 Recreational Boats - Inboards (including inboard/outdrives and inboard cruisers): Calculation Of Emissions And Vehicle Populations

Emissions: Emissions Data was taken from the Emissions Factor reference section II-3 [5]. The accuracy of this data was rated as being very low by the EPA. Most inboard outdrives are powered by automotive gasoline engines. Inboard cruisers are powered by a variety of engine types, including gas and diesel. Diesel engine emission factors are based on tests of engines from Coast Guard vessels. Gasoline emission factors are based on tests of light duty vehicles. Both of these emission factors were given in kg/l. Only gas emission factors were also given in kg/hour. It was assumed that the rate of fuel consumption in gasoline and diesel engines was the same so that the ratio of gas to diesel emissions in kg/l was used to calculate diesel emissions in kg/hour. Once ratios were found for each type of pollutant emitted, worst case figures were used to determine total pollution output.

Population: Inboard/outdrives and inboard cruisers are grouped together in the Statistics Canada data under "Other" (not outboard, canoe, sailboat, rowboat or skiff) [17]. Total households is assumed the same as total boats as these boats are more expensive. Data from the Allied Boating Association was not accurate enough to calculate an adjustment factor for inboards.

Total hours of use per year was assumed to be 72 hrs; this was the same as calculated for outboards.

Sample Calculations

Calculating diesel emissions in kg/hour was done in the following way. First, a ratio of diesel emissions to gas emissions in kg/l of fuel used was made for each pollutant. The example below uses sulphur oxides.

Sulphur Oxides (Diesel Fuel) = 3.2 kg/l

Sulphur Oxides (Gas Fuel) = .77 kg/l or .008 kg/hour [5]

Next, the ratio of diesel to gas emissions in kg/l was calculated.

Ratio Diesel/Gas = (3.2 kg/l) / (.77 kg/l)
= 4.156

A one to one fuel consumption ratio was assumed, and the ratio calculated above was applied to the emissions factor rating for gasoline engines in kg/hour to get the emissions for diesel engines in kg/hour.

SOX Diesel (kg/hour) = SOX Gas (kg/hour) * Ratio Diesel/Gas
= .008 kg/hour * 4.156
= .033 kg/hour or 33 g/hour

Since sulphur oxides from diesel engines are higher than from gas engines, the diesel emission rate was used. The assumption would tend to overestimate the total emissions from recreational boats. Total grams of pollutant emitted was then calculated. In the example below, the emission rate of sulphur oxides was determined for 1987.

Total SOX (tonnes/year) = Total Inboards * Use * SOX emissions
= 31000 * 72 hrs/year * 33 g/hour
= 31000 * 2376 g/year
= 73.7 tonnes/year

3.2.9 Snowblowers: Calculation Of Emissions And Vehicle Populations

Emissions: The emission data that was used for the calculations was obtained from Table II-5-1 [5]. The engines described in the table were small 2-stroke and 4-stroke, air-cooled, gasoline-powered motors. The 2-stroke data was used in the calculations. About 89 % of the 44 million [7] engines in this category are used in lawn and garden applications. This value was based on an annual usage was 50 hours with a 40 % load factor as stated in [5].

Population: The data was collected from Statistics Canada [17] for Ontario for May 1980, March 1984, and May 1987. The data was not available for any intermediate year.

Sample Calculations

Carbon Monoxide (1987):
Gasoline-powered snowblowers,
Total CO emitted = # units * EF
= 527 units * 33400 grams/unit*year
= 17.6 tonnes/year

3.2.10 Lawnmowers: Calculation Of Emissions And Vehicle Populations

Emissions: The information that was used was the same as that used in the calculation of the snowblower emissions since most lawnmowers are gasoline-powered and have 2-stroke, small general utility engines. The same assumptions were used as for the snowblowers.

Population: The values used were obtained for the same years as for the snowblowers [17].

Sample Calculation

Carbon Monoxide (1987):
Gasoline-powered lawnmowers,
Total CO emitted = # of units * EF
= 406 units/year * 33,400 grams/unit
= 47 tonnes/year

3.2.11 Snowmobiles: Calculation Of Emissions And Vehicle Populations

Emissions: The emission data was obtained from the EPA reference manual [5] The average snowmobile engine displacement was estimated as 362 cm^3 which under normal operating conditions had a fuel consumption of 0.94 gallons per hour. On average, the snowmobiles were used 60 hours per year and the sulphur content of the fuel was 0.043% by weight as stated in [5].

Population: The snowmobile population was obtained from Statistics Canada [17]. The number of snowmobiles was calculated by adding the number of households with one snowmobile to the number of households with two or more snowmobiles (the households with 2 or more snowmobiles were multiplied by two). It was assumed that no households would have more than two snowmobiles.

Sample Calculation

Carbon Monoxide (1980):

Total CO emitted = # of units * EF
= 360,000 units/year * 58,700 grams/unit
= 2.1E04 tonnes/year.

4.0 AUTOMOTIVE POLLUTION CONTROL SYSTEMS

4.1 Pollution Control Mechanisms

The pollution control systems currently in use in light-duty and heavy-duty vehicles are outlined in Table 4.1. A description of each pollution control system is given below. Each section discusses the system's purpose, its design, any common design variations or modifications used, and the vehicle types in which it is used.

4.1.1 Oxidation Catalytic Converter

Purpose: This system removes unburned hydrocarbons and carbon monoxide (CO) from the engine's exhaust gas stream. The mechanism was initially introduced in the 1975 model year [19].

Design: This system is located between the exhaust manifold of the engine and the muffler. The converter has a stainless steel outer shell for durability and corrosion resistance. Heat shields and insulating pads are needed around the converter due to the high operating temperature of the converter shell. This temperature can reach 300°C to 400°C [19].

Two converter designs are currently used, the monolith and the pellet type. In both types, the catalyst mix is about 70% platinum and 30% palladium. With the monolith design, the catalyst is deposited on a ceramic honeycomb matrix contained in the converter shell. A flow diffuser ensures a uniform gas flow through the matrix, and a mesh screen surrounding the matrix protects the monolith from damage due to mechanical or thermal shocks [19].

The pellet type converter has the catalyst deposited on the surface of alumina (Al_2O_3) pellets 1/8" to 3/16" in diameter. In the converter, these pellets are contained between baffles which also direct the exhaust gas flow through the catalyst bed. A drain plug in the base of the converter allows

TABLE 4.1

POLLUTION CONTROL SYSTEMS CURRENTLY USED IN MOTOR VEHICLES IN ONTARIO

Vehicle Type	oxidation catalyst	3-way catalyst	exhaust gas recirculation	air pump	other possible modifications
passenger car - gasoline	for some smaller 4-cylinder cars only with increased noble metal loadings and larger catalyst volumes	closed loop system, need electronic feedback control of carburetor (ECU, oxygen sensor, ..) some systems have added oxidation catalyst	used in most vehicles may have electronic controls	pulse air or Reed valves used	retarded spark timing, high energy ignition mechanical or electronic fuel injection fast burn technology, stratified charge engine early fuel evaporation, heated air intake manifold electronic control of spark timing, EGR, air injection
passenger car - diesel	not required	not required	mechanical or electronic controls used	not required	particulate trap required - still under development difficult to meet 0.62 g/km NOx emission level
light duty truck - gasoline	some can use	most have added oxidation catalyst system	used in most vehicles may have electronic controls	air pumps used	
light duty truck - diesel			mechanical or electronic controls used	not required	
heavy duty vehicle - gasoline (LHDGV)	used with vehicles <14000 lb or 6349 kg GVWR	not currently available due to high exhaust gas temperature	electronic controls required	air pump used	carbureter recalibration, manifold and combustion chamber redesign, automatic choke, early fuel evaporation, heated air intake, ignition timing retard evaporative hydrocarbons: charcoal bed in air cleaner, and charcoal canisters for fuel tank
(HHDGV)	catalyst system not technically feasible at present due to high exhaust gas temperature no need yet for catalyst technology		electronic controls required	air pump used	
diesel (LHDDV) (MHDDV) (HHDDV)	problems with particulate plugging and overheating	not technically feasible yet	electronic controls required limited use due to particulate wear on engine		injection timing retard, modified fuel injection system, redesigned spray tip design, compression ratio, combustion chamber shape, and in-cylinder air motion turbocharging and aftercooling, thermal insulation for engine electronic controls under development for injection timing, EGR, fuel feed rate particulate traps under development - problems with plugging and overheating

the pellets to be removed and replaced. The pellet type system uses a lower platinum loading, but it is larger, offers more resistance to exhaust gas flow, and is not as durable as the monolith type design. Due to its greater thermal inertia, the pellet system takes longer to heat up to reaction temperature [19].

On the catalytic surface, the hydrocarbon is converted to water (H_2O) and carbon dioxide (CO_2) and the carbon monoxide (CO) is converted to CO_2 by oxidation on a catalyst surface; the catalyst efficiency is about 90%. The nitrogen oxides (NO_x) contained in the gas stream, however, are not affected. These reactions are exothermic so that the converter temperature is about 90°C higher than the exhaust gas temperature. The catalyst reactivity is low until the catalyst bed reaches about 250°C. Extra air is required for the oxidation reactions; this can be provided by an air injection system which pumps air into either the exhaust manifold or the converter [19].

This is an open-loop catalytic oxidation system which means that there is no feedback control of the fuel flow into the carburetor. Concurrent with the development of the oxidation catalytic converter modifications, have also been made to the engine and its operating parameters in order to optimize fuel efficiency, driveability, and emission reductions. These include using exhaust gas recirculation (EGR), an air pump or pulse air, and a heated intake manifold. Changes to the parameters include using a reduced compression ratio, retarded spark timing, and a leaner air/fuel ratio. A conventional carburetor or mechanical fuel injection can be used [20].

Applications: With the current standards for light-duty vehicles, this system can only be used for some of the smaller, lightweight, 4-cylinder compacts and subcompacts; these account for up to approximately 5% of the total passenger car sales [20]. In order to meet 1987 standards larger catalyst volumes and increased noble metal loadings are required. This system is also applicable to approximately 5% of the light-duty trucks population [20].

This technology is only feasible for light heavy-duty gasoline engines (HDGE) (GVWR < 14000 lb or 6349 kg); for larger HDGE, the exhaust gas temperature overheats the convertor. With heavy-duty diesel engines (HDDE), particulate contamination plugs the converter during reduced engine loads when the exhaust gas temperatures are low. When the exhaust gas temperature increases with increasing engine load, the particulates burn and overheat the convertor [14].

4.1.2 Three-Way Catalytic Converter

Purpose: This convertor removes unburned hydrocarbons, CO, and NO_x from the exhaust gas stream of the engine [20]. The three-way catalytic converter was first introduced in 1978 by Ford and General Motors [19].

Design: As with the oxidation catalytic converter, this system is located between the exhaust manifold and the muffler system. This converter is also made of stainless steel, and heat shields and insulation again surround the shell. In the front half of the convertor where the exhaust gas first enters, the oxidation/reduction catalyst used is a mixture of platinum and rhodium on a monolithic substrate. This catalyst simultaneously oxidizes the hydrocarbons and CO and reduces the NO_x. In the rear half in a second catalyst bed, only platinum is used. This second half oxidizes any remaining hydrocarbons and CO left in the gas stream [19].

Some systems have an added oxidation catalyst bed located after the three-way converter bed. These systems have been shown to have higher NO_x and CO emissions. In the added oxidation bed, some of the ammonia (NH_3) formed in the three-way bed is converted back to NO_x. As well, the total amount of Platinum and Palladium used in this system is approximately the same as that in the system consisting of only a three-way catalytic converter. This results in a reduced catalyst loading in the catalyst beds. During cold-start conditions when the converter is least efficient, this reduced loading leads to increased CO emissions.[21]

This three-way catalytic converter system requires electronically controlled feedback fuel management. This is provided by an electronic control module linked to an oxygen sensor in the tail pipe, and a variable air/fuel ratio controller. To improve fuel consumption, there may also be:

- electronic control of the spark timing,
- exhaust gas recirculation (EGR), and air injection,

into the exhaust manifold or converter [20].

Applications: This system is required on most passenger cars and light-duty trucks. With light trucks, some use an added oxidation catalyst bed to further reduce hydrocarbons and carbon monoxide in the exhaust gas.[20] This technology is not currently available for heavy-duty gasoline and diesel engines since the converter presently cannot withstand the high exhaust gas temperatures [4].

4.1.3 Exhaust Gas Recirculation (EGR)

Purpose: This engine modification is used to control NO_x emissions [19]. The first EGR systems were added to vehicles in the early 1970's.

Design: The air/fuel mixture entering the carburetor is diluted with a small amount (6-14%) of the exhaust gas recirculated from the exhaust manifold. This hot gas reduces the O_2 and fuel concentration and so reduces the maximum temperature that can be attained in the cylinders. Since NO_x formation decreases with decreasing temperature, NO_x emissions are reduced. However, the maximum engine power decreases and particulate emissions increase. EGR is not required during idle, during wide-open throttle, or for cold engine conditions.[19]

To add the EGR system to the engine, the intake manifold has to be redesigned to pipe exhaust gases from the exhaust system without using external pipes. An EGR valve meters the flow or exhaust gases to the intake manifold in response to the intake manifold vacuum [19]. Engine modifications may be required to optimize fuel economy. These modifications

may include increasing the compression ratio in the cylinders and advancing the spark timing [21].

Studies have indicated that, in light-duty vehicles, 80% NOx control can be achieved with 20% exhaust gas recirculation. However, driveability problems will occur above 15% EGR. With the use of electronic EGR control and "fast-burn" technology, the maximum EGR rate can be increased to 35% for a resultant 95% reduction in NO_x emissions without loss of driveability. "Fast-burn" reduces the time from spark plug firing to the almost complete combustion of the fuel in the cylinders. This is achieved either by adding an extra spark plug or by redesigning the combustion cylinder to increase the in-cylinder turbulence [21].

Applications: This system is used in conjunction with oxidation catalytic and three-way catalytic systems in light-duty gasoline and diesel engines. Mechanical controls can be used in gasoline vehicles, while diesel vehicles need the additional precision of electronic controls to decrease fuel consumption [20].

Heavy-duty gasoline and diesel vehicles also use this system, but it has limited application for the diesel vehicles because the recirculated particulates increase engine wear and plug the air inlet system. The smoke, fuel consumption, and hydrocarbon emissions also increase which adversely affects the driveability and durability of these engines. For these diesel engines, electronic controls are required to prevent loss of durability and driveability [22].

4.1.4 Air Injection

Purpose: Further oxidation of the hydrocarbons and CO in the hot gases leaving the engine's exhaust manifold is obtained [19].

Design: By adding fresh air into the engine exhaust manifolds or at the exhaust ports, the hydrocarbons and CO are further oxidized to H_2O and CO_2.

This system consists of either a belt-driven air pump which supplies a high volume of low pressure air to the injection system, or aspirator valves which use exhaust pressure pulsations to draw air into the exhaust system. Air is drawn through a check valve to the exhaust manifold which distributes air to tubes where it is directed to the exhaust ports. The one-way check valve prevents exhaust gas from flowing back through the aspirator valve or air pump [19].

Air injection is also required for gasoline vehicles equipped with a catalytic converter. The additional air is required for the oxidation reactions occurring with the catalyst beds. Electronic control of the air injection will improve fuel consumption [19].

Applications: An air injection system is standard equipment in all light-duty gasoline passenger cars and trucks, and in heavy-duty gasoline vehicles [20]. Diesel engines contain enough O_2 in the exhaust gases for oxidation reactions to occur [22].

4.1.5 Positive Crankcase Ventilation (PCV)

Purpose: About 20% of the possible hydrocarbon emissions from the automobile are fugitive emissions evaporating from the crankcase. Most of these emissions are unburned fuel and combustion byproducts which escape past the piston rings in the cylinders during the compression and power strokes. This system prevents hydrocarbon emissions from escaping from the engine's crankcase into the atmosphere; it also removes the mixture from the crankcase area [19]. The first device was installed on vehicles in 1961 [19].

If these products were left in the crankcase, the hydrocarbon vapours could dissolve in the crankcase oil reducing its viscosity and lubricating properties, and the vapour build-up could increase the crankcase pressure causing seal leaks. Moisture in the vapours could condense and form a

sludge with the hydrocarbons, soot, and dust; by reacting with the fuel, fuel additives, and any products, the moisture could also form acidic solutions such as H_2SO_4, HBr, HNO_3, HCl, and H_2CO_3 [19].

Design: Fresh air to purge the crankcase comes from an inlet hose connected to the air cleaner. The other end of the hose enters the crankcase through a cap located on top of the rocker arm of the crankcase. Another hose, containing the one-way PCV valve, connects the engine's crankcase to the intake manifold. Air flows from the air cleaner through the crankcase into the PCV valve line. The vapour mixture is then fed into the intake manifold of the carburetor. This completely ventilates the engine and prevents crankcase vapours from escaping from the engine to the atmosphere. Fuel economy is increased since the unburned hydrocarbons are returned to the intake manifold where they are fed into the carburetor [19].

Applications: This closed PCV system has been standard equipment on all cars and light-duty trucks since about 1968 [19].

4.1.6 Evaporative Emission Control System (EEC)

Purpose: The EEC system reduces non-exhaust hydrocarbon emissions by preventing the escape of gasoline vapours from the fuel tank, carburetor vents, carburetor throat, and intake manifold. These vapours account for 20% of the hydrocarbon emissions from the vehicle [19]. All domestic vehicles had an EEC system starting in 1971 [19].

Design: The vapours collected from the fuel tank, carburetor vents, carburetor throat, and intake manifold are trapped by the EEC system in a storage canister containing activated carbon. This canister is located in the engine area. Purge air flowing through the charcoal bed removes the hydrocarbon molecules. This purge air with the released vapours is then directed to the intake manifold. As well as reducing pollution, the vehicle's fuel economy is increased because the hydrocarbons are returned to the carburetor through the intake manifold [19].

On the fuel tank, a special filler cap prevents liquid fuel spillage due to gasoline surges in the tank or heat expansion and vapour escape. As well, overfill-limiting devices on the tank prevents the complete filling of the fuel tank leaving a space inside the fuel tank for fuel expansion. A liquid vapour separator is located between the fuel tank and the storage canister. This prevents any liquid fuel from the fuel tank from reaching the storage canister and overloading its capacity. Carburetor vents on the fuel bowl above the carburetor releases vapours from the bowl to prevent pressure buildup and flooding of the engine [19].

Applications: An EEC system is standard equipment on all gasoline passenger cars, light trucks and heavy-duty vehicles [19, 4].

4.1.7 Fuel Tank Restrictor

Purpose: This restrictor prevents leaded gas from being used in vehicles equipped with catalytic convertors. These vehicles require unleaded gas since lead additives would poison the catalyst surfaces [23].

Design: A restriction is placed in the filler tube of the gasoline tank. This prevents the entry of the larger leaded fuel nozzles at gasoline filling stations. Misfuelling, using leaded gasoline in a catalytic converter equipped vehicle, irreversibly destroys the catalyst surface. The converter can be completely deactivated by using about ten tankfuls of leaded gasoline. Other effects of leaded gasoline include the plugging of the converter with lead compounds and the deactivation of the oxygen sensor in computer controlled engines. Both of these effects increase the fuel consumption. Misfuelling rates of up to 10% for passenger cars and 20% for trucks have been observed [19, 23].

Applications: This restrictor is present on all vehicles equipped with catalytic convertors [19].

4.1.8 Particulate Traps

Purpose: The particulate trap, still under development, is being added to diesel cars and trucks to remove particulates from the exhaust gases [22].

Design: This trap is located in the exhaust system of the vehicle. The particulates are caught in a ceramic matrix where they are then oxidized by the hot exhaust gases. One difficulty with the traps is the need to burn the particles that are collected so that the trap does not become plugged. Plugging of the trap would increase the back pressure in the engine and increase the particulate emission levels. The oxidation or combustion rate of the particulates must also be controlled so that the trap does not overheat. The mechanical durability of the trap is also of concern [24].

Applications: Traps are in use in some light-duty diesel engines (LDDE) although further development is still occurring since there is evidence of mechanical failure at relatively low mileages. For heavy-duty diesel engines (HDDE), the traps are not yet technically feasible. The exhaust temperature is not hot enough in HDDE to oxidize the trapped particles. As well, the higher volumetric exhaust flow requires larger sized traps in order to avoid a large back pressure. These traps are still under development [25].

4.1.9 Turbocharging and Aftercooling

Purpose: This system is used with heavy-duty diesel vehicles to control NO_x and particulate emissions [22].

Design: In these engines, a gas turbine, driven by the exhaust gases, is used to operate a compressor. This compressor compresses the intake air, and so increases the temperature and partial pressure of oxygen in the combustion chamber. This is referred to as turbocharging, and it increases the engine power and efficiency. Particulate emissions are reduced since oxidation of the particulates is enhanced by the high temperature and oxygen

partial pressure. This system on its own, however, increases NO_x emissions since the combustion chamber temperature is increased [4].

An aftercooler, located after the compressor of the turbocharger, cools the hot intake air before it reaches the engine. This decreases the combustion temperature and increases the O_2 partial pressure. The final results are a reduction of the NO_x and particulate emissions as well as an increased power output and decreased fuel consumption. The intake air can be cooled using either air or the engine cooling water as the heat sink [4].

Applications: This combined turbocharger and aftercooling system is present on most heavy-duty diesel vehicles [4].

4.2 Vehicle Pollution Control Systems

The pollution control devices used in each type of vehicle have been described in Section 4.1. The following is a description of the complete vehicle pollution control system for each vehicle category.

4.2.1 Passenger Car - Gasoline

About 5% of the gasoline passenger cars can use an oxidation catalyst system. These are the light-weight, 4-cylinder cars. The rest of the cars, however, are equipped with a three-way catalytic converter as well as an electronic feedback mechanism to control the fuel feed rate. The engine performance may be optimized by using fuel injection timing, and an injection pressure mechanism that alters the feed depending on the engine load. These electronic controls are currently being developed [26].

The vehicles may also utilize electronic controllers to govern the spark timing, exhaust gas recirculation (EGR), and the air injection in order to improve fuel consumption. These mechanisms are still being perfected. The engineers' goal is to optimize engine performance and reduce emissions levels [20].

By delaying the ignition spark in gasoline engines, known as spark timing retard, the peak temperature and pressure in the combustion chamber are reduced. This results in reduced NO_x emissions since NO_x formation depends directly on the temperature and pressure achieved during combustion. The EGR is also used for NO_x control. By recirculating exhaust gas, the peak combustion and temperature is reduced since the gas reduced the partial pressure of oxygen in the combustion chamber. Air injection, by pulse air mechanisms, is used to provide extra air for the catalytic converter. The oxygen in the air is needed to oxidize CO and hydrocarbons; normally there would be insufficient oxygen in the exhaust gas [20].

Preheating the air/fuel mixture can be accomplished by heating the air

intake manifold. This leads to early fuel evaporation, reduced hydrocarbon emissions, and reduced CO emissions during cold starts [21].

Some systems may have an added oxidation catalyst bed, but these have been shown to have increased CO and NO_x emissions [21]. The oxidation catalyst bed converts some of the NO_x reduced in the three-way catalyst bed back to NO_x. As well, a system with an added oxidation catalyst bed contains about the same total amount of oxidation catalyst as the three-way catalyst bed normally would. Consequently, during engine warmup when the catalyst beds are cold and the engine has high CO emissions, the combined catalyst system would have higher CO emissions than one containing only a three-way catalyst bed [21].

In order to optimize the fuel economy, engine durability, vehicle driveability, while simultaneously reducing vehicle emissions, other changes and additions have to be made to the engine. These include varying the air/fuel ratio fed to the combustion chamber to alter the combustion rate and peak combustion temperature of the air/fuel mixture. This directly affects the emission levels of CO, hydrocarbons, and NO_x. Another variable, the compression ratio, affects the final pressure in the combustion chamber before the mixture is ignited. This determines the mixture temperature and peak combustion temperature, and therefore the NO_x emissions. The design of the combustion chamber or cylinder itself affects the burning rate in the cylinders and the fuel efficiency of the engine [20].

4.2.2 Passenger Cars - Diesel

Diesel passenger cars account for less than 5% of Canada's new car sales [20]. Exhaust gas recirculation is required for NO_x control. These may use either mechanical or electronic controls. Electronic controls of the injection timing of the fuel, EGR, and fuel feed rate on diesel vehicles are currently being perfected. The goal is to optimize engine performance and reduce emission levels. Particulate traps are still under development to control the particulate emissions [20].

4.2.3 Light-Duty Trucks - Gasoline

About 5% of these trucks can use an oxidation catalyst system, while the rest are fitted with either a closed loop three-way catalyst system (40%) or a three-way plus oxidation catalyst system (55%). An air pump is used to provide additional air to the catalyst bed [20].

4.2.4 Heavy-Duty Vehicles - Gasoline

Exhaust gas recirculation (EGR) is needed to control NO_x emissions. Spark timing retard, air/fuel enleanment, and air injection are used to optimize fuel consumption, driveability, and emission reductions. Manifold and combustion chamber redesign, early fuel evaporation through a heated air intake, and an automatic choke are other necessary changes [4].

For heavy-duty vehicles less than 14000 lb GVWR, oxidation catalytic converters are available to control CO and hydrocarbon emissions. For heavier vehicles, the converters are neither feasible due to the high exhaust gas temperature nor are they required to meet the current standards. Three-way catalyst systems are not currently available for any heavy-duty weight class division because of the high temperatures involved [22].

To control evaporative hydrocarbon emissions, a charcoal bed located in the air cleaner and charcoal canisters for fuel tank emissions are used to trap the vapour emissions [4].

4.2.5 Heavy-Duty Vehicles - Diesel

For all heavy duty diesel vehicles, NO_x emissions are controlled by

- injection timing retard;
- turbocompounding and aftercooling;
- EGR, and
- thermal insulation of the engine.

Catalytic control is difficult due to problems with particulate plugging and subsequent overheating. A reduction catalyst is not yet available due to durability and design problems [22].

In heavy duty diesel engines, a gas turbine, driven by the exhaust gases, is used to operate a compressor. This compressor compresses the intake air, and so increases the temperature and partial pressure of oxygen in the combustion chamber. This is known as turbocharging or turbocompounding. An aftercooler, located after the compressor of the turbocharger, cools the hot intake air before it reaches the engine. This decreases the combustion temperature and increases the O_2 partial pressure. The final results are a reduction of the NO_x and particulate emissions as well as an increased power output and decreased fuel consumption [22].

Electronic controls for EGR are required so that small amounts of exhaust gas can be recirculated without loss of durability and driveability. Mechanical controls are not sufficient to improve fuel consumption. Currently, EGR has limited use due to particulate wear and plugging of engine components [22].

Using engine insulation, insulating the exhaust system on heavy-duty diesel vehicles, means that the energy ejected from the cylinders leaves directly through the exhaust system. This reduces the load on the engine cooling system.

Modifications to the fuel injection system, including changes to the spray tip design, combustion chamber shape, and in-cylinder air motion are necessary to optimize the fuel economy. As well, changes to the cylinder heat inlet port and compression ratio can be used to optimize the fuel economy as well [22].

Particulate traps to intercept particulates are currently under development. The main problem is trap regeneration since the exhaust gas temperature is not hot enough to burn the particles caught by the trap. Mechanical trap durability is also a concern. As well, larger traps are needed than for

light-duty diesel vehicles because of the larger volumetric flow of the exhaust gases [24, 25].

5.0 EFFECT OF TAMPERING ON VEHICLE PERFORMANCE AND OPERATION

5.1 Tampering

In 1988, the Ontario Ministry of the Environment conducted an exhaust emission surveillance of in-use cars [27]. It found that only 26% of the cars sampled passed the standards for hydrocarbon, CO, and NO_x. The other 74% failed one or more of the standards, and about 18% of the vehicles failed all three standards [27].

The causes of the excessive emissions problem have been identified as being due to:

- poor maintenance,
- engine maladjustments, and
- disabled control systems.

Normally, the emissions should increase slightly with age. However, in a test conducted by the California Air Resources Board in 1976, 50% of the one-year old cars tested failed inspection tests. This compared with a 3% failure rate off the assembly line. The failures were mainly due to calibration maladjustments [28].

Tampering with emission control systems may take the form of:

- PCV hose rerouting and plugging,
- PCV and disabling EGR valve disabling, and
- control system component removal.

From the 1985 Motor Vehicle Manufacturer's Association survey, it was found that on an average of 7% of the cars and 15% of the trucks have had their catalytic converters removed [29].

The tampering rates on passenger cars and light duty trucks for the different control systems was also assessed in 1985 by a U.S. EPA survey.

These tampering rates are shown in Table 5.1. Overall, 19% of passenger cars and 22% of light-duty trucks have undergone some form of tampering. Fuel switching was found in 8% and 13% of the passenger cars and light duty trucks respectively [28].

5.2 Misfueling

Misfueling, the practice of using leaded gasoline in a vehicle equipped with a catalytic converter, is another major problem with catalyst equipped vehicles. In Canada, an average misfueling rate for cars of 12% has been observed at gas stations. The rate was in a range of 8% to 35% depending on the city. Of the misfueling, 91% was done using a tampered fuel tank restricter, 4% used a substituted nozzle, and 3% used slow filling [30].

Misfueling is hindered by a fuel inlet restricter placed in the inlet to the fuel tank. The larger nozzles used for the leaded gas at the gas stations then cannot fit into the fuel inlet. Misfueling can be accomplished by:

- Removing the restricter,
- replacing the leaded fuel nozzle with one meant for unleaded fuel, and
- using a nozzle adaptor [30].

The lead in the leaded gas irreversibly poisons the catalyst and plugs the converter. It also impairs the oxygen sensor which increases the fuel consumption. As a result, misfueling reduces the exhaust system and spark plug life, and plugs the EGR valves.

From a series of U.S. E.P.A. tests, it was found that misfueling affected the conversion efficiency of hydrocarbons more than that of NO_x and CO [31]. The increase in hydrocarbons was mainly in the reactive, non-methane fraction (+321%) rather than in the methane fraction (38%). The test found:

TABLE 5.1

TAMPERING RATES BY VEHICLE TYPE [26]

System	Passenger Cars	Light-Duty Trucks
catalytic converter	4%	10%
filler neck restrictor	7%	10%
air pump	6%	11%
positive crankcase ventilation	5%	5%
evaporative emission control	4%	4%
exhaust gas recirculation	7%	8%
overall	19%	22%
fuel switching	8%	13%

- nearly a 76% loss in hydrocarbon conversion efficiency following the use of ten tankfuls of leaded gas,
- a 29% decrease in NO_x control, and
- a 45% decrease in CO control.

It is notable that most of the impact of leaded fuel was on the catalyst since the emission levels returned to near baseline levels when new catalytic converters were installed. The oxygen sensors were also affected and were responsible for most of the remaining loss [31].

With frequent or intermittent misfueling, similar increases in the emission rates are found. Most of the catalyst deactivation occurred within the first four tankfuls of leaded fuel [31].

5.3 Changes in Vehicle Performance and Operation

A series of tests were performed by the U.S. E.P.A. in order to determine the effect of single component disablement on hydrocarbon, CO, and NO_x emissions. The resulting effects are shown in Table 5.2. Generally, the effect on fuel consumption was negligible. When more than one component was disabled at a time, it was found that the effects on the emissions were not additive. The emission rate could not be predicted knowing the emission increase due to each component disabled [32].

The effects of malfunctions on fuel consumption due to improper maintenance, engine maladjustment, and tampering are shown in Table 5.3. A fuel economy decrease, or a fuel consumption increase, of up to 15% has been observed. This was usually accompanied by an increase in the hydrocarbon and CO emissions [28].

When vehicles are equipped with catalytic converters, the engine and exhaust system durability is increased. This is a result of the use of the unleaded fuels and the stainless steel in the exhaust system. Reduced engine maintenance should result since there will be less exhaust system corrosion,

TABLE 5.2

EFFECTS OF SINGLE COMPONENT DISABLEMENT ON VEHICLE EMISSIONS [32]

Single Component	Pollutant HC	CO	NOx	fuel consumption
air injection	+8 to +185%	+11 to 260%	slight decrease	slight decrease
oxidation catalyst	+150 to 389%	+59 to 135%	increase	slight decrease
3-way catalyst	+136 to 550%	+110 to 311%	+264 to 2305%	-1.5%
exhaust gas recirculation	slight decrease	slight decrease	+70 to 141%	negligible effect
oxygen: fail lean	+63%	+128%	+103%	
sensor: fail rich	+264%	+531%	-56%	+2%
positive crankcase ventilation	+1 to 48%	+8 to 70%	-2 to -25%	

TABLE 5.3

EFFECT OF MALFUNCTIONS ON FUEL ECONOMY AND EMISSIONS [28]

Fault	Fuel Consumption Increase	Effect on Idle Emissions CO	HC
misfire	6 to 15%	---	increase
rich carburetion	10 to 13%	increase	increase
rich idle mixture	2 to 13%	increase	increase
rich choke	2 to 5%	increase	increase
plugged pcv	3 to 5%	increase	increase
incorrect idle speed	0 to 4%	---	increase
incorrect timing	0 to 7%	---	increase
vacuum leak	0 to 1%	---	increase
poor ignition	1 to 3%	---	increase
faulty valves	0 to 10%	---	increase

and less fouling and corrosion of the engines and spark plugs. However, the increased complexity of the control systems may increase the maintenance costs [20].

The manufacturers optimize fuel economy, emissions, and performance so no engine adjustments are necessary. Removal or disablement of any component would cause a deterioration in the vehicles' fuel economy and performance as well as increasing the emissions [20].

6.0 TRENDS IN MOTOR VEHICLE POLLUTION CONTROL SYSTEMS

The pollution control systems previously described presented the current technology required to meet the regulated emission standards. Evolution of the systems continues, however, as the regulations governing emissions become more stringent and as the manufacturers' gain more experience with the systems' durability, performance, and cost. The current trends in the research and development of pollution control systems for each type of vehicle will now be outlined.

6.1 Light-Duty Vehicles - Gasoline

The main research for light-duty gasoline vehicles is in the continued development of electronic controls for EGR and engine operating parameters such as air injection and fuel feed rate. Secondary air addition may no longer be required since the electronic EGR control provides better air/fuel ratio control. Mechanical EGR control will be phased out [21].

Changes to the engine design include the development of 'fast-burn' combustion chambers, and the replacement of carburetors with mechanically or electronically controlled fuel injection. 'Fast-burn' chambers reduce the time between the spark plug firing and the complete combustion of the fuel. This is accomplished by either increased combustion chamber turbulence or addition of more spark plugs [21].

Another change occurring to the engine is the development of early fuel evaporation systems to reduce cold start hydrocarbon and CO emissions. With a warm intake manifold, fuel vaporization is improved and the air/fuel mixture does not have to be as rich to obtain a combustible air/fuel mixture. Two methods are being developed. The first method is to direct the exhaust gas by the intake manifold to reduce the intake warmup time. This method's usefulness is limited by the thermal inertia of the manifold. The second is to install electrical resistance heating in the intake manifold. The heater is a grid mounted directly under the carburetor which

is used to heat the manifold during cold starts and warmup [21].

There are no major changes expected in catalyst technology. Only two modifications are occurring. The first is the discontinuation of the added oxidation catalyst bed with the three-way catalytic converter. This system has been found to have increased NO_x and CO emissions compared with a three-way catalytic converter. The second modification is the use of a warmup catalyst bed used to reduce cold start emissions. This bed, located close to the exhaust manifold outlet to minimize heat loss, is sized only to handle the exhaust flow during warmup. A monolithic bed design is used to reduce the warmup time by minimizing the effects of thermal inertia [21].

It is notable that Ford has recently announced a substitute for platinum in catalytic converters. The cost saving to the consumer is unknown at this time [33].

6.2 Light-Duty Vehicles - Diesel

For light-duty diesel vehicles, the two main trends are the further development of electronic EGR control and particulate traps. The problems still to be solved with the traps are the traps' mechanical durability and their plugging with particulates [25].

6.3 Heavy-Duty Vehicles - Gasoline

The main research for heavy-duty gasoline vehicles is in the area of electronic control of EGR, ignition timing, and air/fuel ratio. The durability problems with the oxidation catalytic converters are still to be solved. Three-way catalytic converter systems cannot withstand the high exhaust temperature of the gas [4,22].

TABLE 4.1

POLLUTION CONTROL SYSTEMS CURRENTLY USED IN MOTOR VEHICLES IN ONTARIO

Vehicle Type	oxidation catalyst	3-way catalyst	exhaust gas recirculation	air pump	other possible modifications
passenger car - gasoline	for some smaller 4-cylinder cars only with increased noble metal loadings and larger catalyst volumes	closed loop system, need electronic feedback control of carburetor (ECU, oxygen sensor,..) some systems have added oxidation catalyst	used in most vehicles may have electronic controls	pulse air or Reed valves used	retarded spark timing, high energy ignition mechanical or electronic fuel injection fast burn technology, stratified charge engine early fuel evaporation, heated air intake manifold electronic control of spark timing, EGR, air injection
passenger car - diesel	not required	not required	mechanical or electronic controls used	not required	particulate trap required - still under development difficult to meet 0.62 g/km NOx emission level
light duty truck - gasoline	some can use	most have added oxidation catalyst system	used in most vehicles may have electronic controls	air pumps used	
light duty truck - diesel			mechanical or electronic controls used	not required	
heavy duty vehicle - gasoline (LHDGV)	used with vehicles <14000 lb or 6349 kg GVWR	not currently available due to high exhaust gas temperature	electronic controls required	air pump used	carbureter recalibration, manifold and combustion chamber redesign, automatic choke, early fuel evaporation, heated air intake, ignition timing retard evaporative hydrocarbons: charcoal bed in air cleaner, and charcoal canisters for fuel tank
(HHDGV)	catalyst system not technically feasible at present due to high exhaust gas temperature no need yet for catalyst technology		electronic controls required	air pump used	
diesel (LHDDV) (MHDDV) (HHDDV)	problems with particulate plugging and overheating	not technically feasible yet	electronic controls required limited use due to particulate wear on engine		injection timing retard, modified fuel injection system, redesigned spray tip design, compression ratio, combustion chamber shape, and in-cylinder air motion turbocharging and aftercooling, thermal insulation for engine electronic controls under development for injection timing, EGR, fuel feed rate particulate traps under development - problems with plugging and overheating

6.4 Heavy-Duty Vehicles - Diesel

Most of the automotive research seems to be occurring with heavy-duty diesel engines since these have the most problems meeting the current regulations. Electronic control of EGR, variable fuel injection timing systems, and fuel feed rate are currently under development. The goals are to lower NO_x and particulate emissions while also reducing fuel consumption. Mechanical controls have been found to be inadequate to meet these goals [4].

With particulate traps, the two main problems hampering their development are their durability and their ability to be regenerated. These traps must be more durable than those used for light-duty diesel vehicles (LDDV) since heavy-duty diesel vehicles (HDDV) have a longer useful life [22].

Particulate traps for HDDV's must be larger than those for LDDV's to avoid a high back pressure since the exhaust flow rate is higher. The higher exhaust volume and mass flow rate leads to increased particulate levels in the exhaust and a greater plugging problem. Especially if the engine is turbocharged, the exhaust gas is usually not hot enough to oxidize the particles [25].

The three designs of particulate traps currently being developed are a ceramic monolith, a ceramic fibre, and a catalytic radial flow wire mesh design. The monolith design consists of a matrix of open and closed cells. The particulates are collected as the exhaust gas flows through the cells. The back pressure, however, increases rapidly with particulate loading due to the clogging of the trap with ash. These traps do have a high trapping efficiency and are tolerant to temperature variations [25].

The ceramic fibre design consists of cylinders whose walls are strands of crosswound silica-fibre yarn. These cylinders are packed in a canister and the exhaust gases must flow through their walls. Again plugging with noncombustible particulates leads to an increased back pressure [25].

The third design, the catalytic radial flow wire mesh, are cylinders made of

layers of knit stainless steel mesh which are catalyst coated. The density of the mesh increases towards the centre of the cylinder. This design is not susceptible to thermal cracking, but it has a lower collection efficiency and causes increased sulphate emissions [25].

The two type of regeneration systems being considered are self-regeneration which would occur during normal vehicle operation and positive regeneration which would occur at set intervals. In both cases, the particulates are oxidized or burned in an oxygen rich environment. The air flow also keeps the trap from becoming too hot. With the self-regeneration system, without catalysts, the ignition temperature of the particulates is about 500 to 600 C. With catalysts, this temperature can be as low as 200 C. Catalytic fuel additives or catalytic coatings being researched are usually organometallics containing copper, lead, calcium, or manganese. One problem that still occurs is the plugging of the traps by the additives [25].

With positive regeneration, the particulate trap is heated at set intervals to oxidize the particulates. This is accomplished by:

- using a diesel oil burner,
- electrical heating,
- catalyst injection into the exhaust stream to lower the ignition temperature, or
- hydrocarbon and CO oxidation to increase the trap temperature [25].

Research is also being conducted to overcome the problems of plugging and overheating of the oxidation catalytic converters. Three-way catalyst systems are not yet available due to the design and durability problems experienced with the reduction section [22].

Modifications to the diesel fuel are being advocated by some manufacturers such as Mercedes Benz. A decreased sulphur content in the diesel fuel would reduce the plugging of the particulate traps by noncombustible sulphur products. Fuel additives containing catalysts are also being researched as a means of aiding the oxidation of the particulates in the traps [22].

Simple retarded injection timing is being phased out since fuel usage, particulate matter emissions, and hydrocarbon emissions increase. As well, more advanced and effective NO_x control systems are available. Improvements to the turbocharger and aftercooler systems are still being developed [22].

Some research has been conducted on injecting water into the diesel fuel to form an emulsion. This has been found to reduce NO_x emissions since the peak combustion temperature is lowered. Little change in hydrocarbon and particulate emissions or fuel usage occurs. However, problems with this system include reduced engine durability, increased engine complexity, and water storage problems [22].

7.0 ALTERNATIVE FUELS

There are four main factors driving the alternative fuels market; these are:

- economy,
- supply
- security, and
- emissions.

The two main alternative fuels being studied are natural gas and propane. Both are inexpensive, are under North American control, and are readily available. Carbon dioxide, nitrogen oxides and hydrocarbons emissions are substantially reduced from these fuels relative to gasoline [34].

The main thrust of work with natural gas and propane is for use in diesel engines. Diesel engines use compression to ignite the fuel. Since neither propane nor natural gas will ignite this way, they must be combined with diesel fuel. Work is currently being done to change the diesel engine so that spark plugs could be used, eliminating the need for diesel additives in the natural gas or propane [34].

Since conversion to alternate fuels is very expensive, it is considered useful only in special situations. Prototype buses running on natural gas are scheduled to appear soon in the Mississauga area. It is hoped that these buses will take over the Toronto market currently occupied by electric trolleys. The cost of conversion to natural gas was approximately ten thousand dollars; the payback period was expected to be short less than 1 year [35].

All cars in the present fleet that run on natural gas or propane have been converted from gasoline engines. Since these engines were optimized to run on gasoline with minimum emissions, the emission reductions are negligible. Currently work is being done on an electronic fuel injection system that will accept alternative fuels; it will make any necessary compensations so that the engine will run optimally [34].

Other alternative fuels being studied are methanol, ethanol, and hydrogen. Although the first two fuels are currently used as octane boosters, they are too expensive for large scale use. Methanol is not only more expensive per litre, but it also contains fewer BTU's per litre so that more fuel is required. Mass conversion to ethanol, derived from corn husks, would cause a major shift in agriculture from food production to fuel production. This not considered to be a positive step considering the growing world population and smaller percentage of farm land [34].

Hydrogen, on the other hand, is considered by many to be the ideal fuel [35]. It is inexpensive, readily available, and virtually pollution free. The main problem with it is the lack of available technology for storage and handling. Hydrogen, the smallest known molecule, can penetrate metal and is therefore difficult to contain or control by the use of valves. Keeping it in a liquid form requires temperatures less than -200 ^{o}C. Technology will not be available to handle this fuel for at least another 15 to 20 years. A non-polluting fuel cell which can use either methanol or hydrogen is currently being researched for industrial use. It may prove promising for the transportation sector [35].

8.0 THE MARKET INFLUENCE ON POLLUTION CONTROL SYSTEMS

Many factors influence manufacturers decision either to produce a vehicle model specifically for a Canadian market or to sell a model in Canada which meets the United States pollution control standards. These factors include:

- the cost of compliance,
- the market share of the manufacturer,
- the stringency of the standards, and
- the technical feasibility of meeting the standards.

Since the Canadian market is much smaller than that of the United States, economic decisions will be of major importance. The automotive manufacturing industry has stated that for car or truck models whose annual sales are less than a few thousand, it may be more cost effective to install a US federal or California emissions control system than to develop a unique Canadian calibration. The US system would already have been certified for the US standards which are currently the same as those in Canada [36].

No new technology needs to be developed by North American manufacturers since the necessary systems to meet the emission standards are on all cars sold in the United States. However, 28% of the cars sold in Canada are manufactured by overseas or offshore firms. The rest of the vehicles sold are made either in the United States, 54%, or in Canada, 18% [20].

Some of these overseas manufacturers, such as Suzuki, Lada, Dacia, Skoda, and Innocenti, do not sell their vehicles in the United States. As a result, they do not have vehicles which comply with the United States emission standards. The cost of developing and certifying emission control systems for Canada has to be recovered on their relatively low sales volume; their costs of compliance are then higher than for North American manufacturers. These costs will either be added to the retail cost of the vehicles which would decrease the vehicles' price advantage or the costs will be absorbed by the manufacturers which would lower their profits. The net effect, in either case, would be a weakened competitive position and,

possibly, a shift in market sales to the North American manufacturers [20].

The additional costs incurred to produce a Canadian system include research and development costs, tooling costs, and certification costs. Certification costs are about $250,000 per engine family or emission control system configuration [36].

However, any incentive to produce a unique Canadian system is reduced since the Canadian and US standards for passenger cars and light duty trucks are now the same. Past experience in the United States, where the US 49-state standards have lagged the California standards by only a few years, has shown that any market perturbations are short-lived. Basically, the only difference is in the control system calibration. The hardware is essentially the same throughout the United States [37].

As well, pollution control systems are expected to continually evolve as regulations become more stringent and as more knowledge is gained on the cost, durability, and performance of the control systems [38].

If, at any time, the Canadian standards are made more stringent than those of the United States (except possibly California), manufacturers may decide not to develop a model with a unique Canadian calibration. The main reason is again the small Canadian market size relative to that of the United States. Consequently, model availability would be reduced. However, if a California system has been certified for the same or more stringent standards, that may be offered [20].

Another factor, which has so far only affected diesel car sales in the United States, has been the technical feasibility of meeting any proposed standards. If the technology is unavailable or is still being developed, models may again be withdrawn from the market either permanently or until a technical solution has been found.

9.0 PROJECTED COSTS OF POLLUTION CONTROL EQUIPMENT

9.1 Method

In order to determine the cost effectiveness of the various possible control options for light and heavy duty gasoline and diesel vehicles, it was necessary to determine the future costs of each control option per tonne of pollutant reduction. Once these were available for the different options, comparisons could be made to determine the most effective control option.

The first step necessary in this analysis was to estimate the future vehicle populations and the expected pollutant emission levels. The pollutants emission level of a base case in which no additional pollution control equipment was added was also required. This allowed the calculation of the reduction in pollutant level caused by the additional control equipment.

Next, the cost to the consumer or the retail price equivalent (RPE) necessary to upgrade light and heavy duty vehicles to meet the proposed emission standards was needed. The retail price equivalent is the cost, at the retail level, of the pollution control system. These values were found from various sources, and they are tabulated in Table 9.1.

Table 9.2 outlines the relative usage of the various control systems on light duty vehicles before and after the 1987 standards were implemented.

Once the costs were determined per vehicle and knowing the vehicle populations, estimates of the total future costs for the options could be calculated. As well, the present value of the costs was found using a 10% discount rate. The final step was then to calculate the cost of the pollution control options per tonne of pollutant reduction. All the costs in the following analysis are in 1987 canadian dollars unless otherwise stated.

TABLE 9.1

COST OF MOTOR VEHICLE POLLUTION CONTROL SYSTEMS

Vehicle Class	Fuel	Source	Upgrade	Retail Price Equivalent (RPE)	Monetary Unit (Original)	RPE (1987 $ Can)	Reference
Light Duty Vehicle - Passenger Car	Gasoline	Toyota	oxidation catalyst system	$227	1983 $ Can	$266	36
		Honda	"	$410-$610	1983 $ Can	$716	36
		Authors of [36]	"	$390	1983 $ Can	$458	36
		Toyota	non-catalyst system	$182	1983 $ Can	$214	36
		Honda	"	$475	1983 $ Can	$558	36
		Authors of [36]	"	$130	1983 $ Can	$153	36
		Authors of [36]	non-catalyst to three-way system	$400	1983 $ Can	$470	36
		EPA		$360-$510	1983 $ Can	$599	36
		Honda		$480-$805	1983 $ Can	$945	36
		Toyota		$418	1983 $ Can	$491	36
		Renault		$940	1983 $ Can	$1,103	36
		Ford	oxidation to three-way	$175	1983 $ Can	$205	26
		Chrysler	catalyst system	$210	"	$247	26
		Vokswagon	"	$155	"	$182	26
		Renault	"	$940	"	$1,103	26
		Toyota, Honda	"	$350.00-$550.00	"	$528	26
		GM (EPA Estimate)	"	$110.00-$240.00	"	$205	26
		EPA	"	$100	"	$117	36
		Average cited in [26]	"	$235	"	$276	26
		Average cited in [20]	oxidation to three-way catalyst system	$170	1983 $ Can	$200	20
		EPA	oxidation to three-way	$240	1983 $ Can	$282	36
		Ford	plus oxidation catalyst	$175	1983 $ Can	$205	36
		Toyota	"	$452	1983 $ Can	$531	36
		Average cited in [20]	oxidation to three-way	$266	1983 $ Can	$312	20
		GM	catalyst system	$175	"	$205	20
		Others cited in [20]	"	$450	"	$528	20
			positive crankcase ventilation	$15	1970 $ Can	$48	39
			evaporative emission controls	$10	"	$32	39
			exhaust gas recirculation	$25	"	$80	39
Light Duty Vehicle - Passenger Car	Diesel			<$900.00	1983 $ Can	$1,057	20
Light Duty Vehicle - Light Truck	Gasoline	Average cited in [20]	upgraded to three-way catalyst system	$215	1983 $ Can	$252	20
4-cylinder		U.S. EPA	no catalyst to oxidation catalyst	$199	1985 $ Can	$216	20
		U.S. EPA	no catalyst to three-way catalyst	$348	1985 $ Can	$377	20
		U.S. EPA	oxidation to three-way catalyst	$149	1985 $ Can	$162	20
		U.S. EPA	oxidation to three-way + oxidation	$181	1985 $ Can	$196	20
		U.S. EPA	three-way to three-way + oxidation	$32	1985 $ Can	$35	20
		Average cited in [20]		$162	1985 $ Can	$176	20

TABLE 9.1

COST OF MOTOR VEHICLE POLLUTION CONTROL SYSTEMS

Vehicle Class	Fuel	Source	Upgrade	Retail Price Equivalent (RPE)	Monetary Unit (Original)	RPE (1987 $ Can)	Reference
6-cylinder		U.S. EPA	no catalyst to oxidation catalyst	$243	1985 $ Can	$263	20
		U.S. EPA	no catalyst to three-way catalyst	$430.00	1985 $ Can	$466	20
		U.S. EPA	oxidation to three-way catalyst	$187.00	1985 $ Can	$203	20
		U.S. EPA	oxidation to three-way + oxidation	$253.00	1985 $ Can	$274	20
		U.S. EPA	three-way to three-way + oxidation	$66.00	1985 $ Can	$72	20
		Average cited in [20]		$214.00	1985 $ Can	$232	20
8-cylinder		U.S. EPA	no catalyst to oxidation catalyst	$282.00	1985 $ Can	$306	20
		U.S. EPA	no catalyst to three-way catalyst	$503.00	1985 $ Can	$545	20
		U.S. EPA	oxidation to three-way catalyst	$220.00	1985 $ Can	$239	20
		U.S. EPA	oxidation to three-way + oxidation	$316.00	1985 $ Can	$343	20
		U.S. EPA	three-way to three-way + oxidation	$95.00	1985 $ Can	$103	20
		Average cited in [20]		$255.00	1985 $ Can	$276	20
		Average cited in [20]	Average for all LDGT	$201.00	1985 $ Can	$218	20
Light Duty Vehicle - Light Truck	Diesel	U.S. EPA	non-electronic EGR	$28.00	1985 $ Can	$30	20
		U.S. EPA	electronic EGR	$59.00	1985 $ Can	$64	20
		Average cited in [20]	average for all LDDT	$47.00	1985 $ Can	$51	20
Heavy Duty Vehicle	Gasoline	U.S. EPA	add oxidation catalyst (LHDGE only)	$173.00	1985 $ Can	$188	4
		U.S. EPA	add evaporative hydrocarbon control	$28.00	1985 $ Can	$30	4
		U.S. EPA	add NOx control	$4.00	1985 $ Can	$4	4
	Diesel	U.S. EPA	NOx control	$34.00	1985 $ Can	$37	4
		U.S. EPA	particulate control	$19.00	1985 $ Can	$21	4
-Light Heavy	Gasoline		exhaust hydrocarbon control	$87.00	1985 $ Can	$94	4
			evaporative hydrocarbon control	$28.00	1985 $ Can	$30	4
			CO control	$87.00	1985 $ Can	$94	4
			NOx control	$4.00	1985 $ Can	$4	4
			particulate control				
			total	$210.00	1985 $ Can	$228	4
-Medium Heavy			exhaust hydrocarbon control				
			evaporative hydrocarbon control	$28.00	1985 $ Can	$30	4
			CO control				
			NOx control	$4.00	1985 $ Can	$4	4
			particulate control				
			total	$40.00	1985 $ Can	$43	4
-Average HDGV			exhaust hydrocarbon control	$67.00	1985 $ Can	$73	4
			evaporative hydrocarbon control	$28.00	1985 $ Can	$30	4
			CO control	$67.00	1985 $ Can	$73	4
			NOx control	$4.00	1985 $ Can	$4	4
			particulate control				
			total	$170.00	1985 $ Can	$184	4
-Light Heavy	Diesel		NOx control	$114.00	1985 $ Can	$124	4

TABLE 9.1

COST OF MOTOR VEHICLE POLLUTION CONTROL SYSTEMS

Vehicle Class	Fuel	Source	Upgrade	Retail Price Equivalent (RPE)	Monetary Unit (Original)	RPE (1987 $ Can)	Reference
			particulate control	$19.00	1985 $ Can	$21	4
			total	$130.00	1985 $ Can	$141	4
-Medium Heavy			NOx control	$384.00	1985 $ Can	$416	4
			particulate control	$19.00	1985 $ Can	$21	4
			total	$400.00	1985 $ Can	$434	4
-Heavy Heavy			NOx control	$934.00	1985 $ Can	$1,013	4
			particulate control	$19.00	1985 $ Can	$21	4
			total	$950.00	1985 $ Can	$1,030	4
-Urban Bus			NOx control	$684.00	1985 $ Can	$742	4
			particulate control	$19.00	1985 $ Can	$21	4
			total	$700.00	1985 $ Can	$759	4
-Average HDDV			NOx control	$544.00	1985 $ Can	$590	4
			particulate control	$19.00	1985 $ Can	$21	4
			total	$560.00	1985 $ Can	$607	4

TABLE 9.2

MOTOR VEHICLE POLLUTION CONTROL SYSTEMS USED

Vehicle Class	Fuel	Year		Control System	Percentage Use in Vehicles	Reference
Light Duty Vehicle - Passenger Car	Gasoline	pre-1987		no catalyst	15%	20
				oxidation catalyst (1)	70%	20
				three-way catalyst (2)	15%	20
		post-1987		oxidation catalyst (1)	5%	20
				three-way catalyst (2)	95%	20
- Light Duty Truck	Gasoline	pre-1987		no catalyst	16%	20
				oxidation catalyst (1)	67%	20
				three-way catalyst (2)	13%	20
				three-way catalyst plus oxidation catalyst	4%	20
		post-1987	4 cylinders	oxidation catalyst (1)	5%	20
				three-way catalyst (2)	38%	20
				three-way catalyst plus oxidation catalyst	57%	20
			6 cylinders	oxidation catalyst (1)	5%	20
				three-way catalyst (2)	38%	20
				three-way catalyst plus oxidation catalyst	57%	20
			8 cylinders	oxidation catalyst (1)	5%	20
				three-way catalyst (2)	43%	20
				three-way catalyst plus oxidation catalyst	52%	20
Light Duty Vehicle - Passenger Car	Diesel	post-1987		new EGR (3)	100%	20
Heavy Duty Vehicle - Light	Gasoline	post-1988		oxidation catalyst	100%	4
				evaporative hydrocarbon control	100%	4
				NOx control	100%	4
- Heavy		post-1988		evaporative hydrocarbon control	100%	4
				NOx control	100%	4
	Diesel	post-1988		NOx control	100%	4
				particulate control	100%	4

Note: Effectiveness:
(1): 90% for CO, hydrocarbon control, 0% for NOx control
(2): 90% for CO, hydrocarbon control, >85% for NOx control
(3): 80% control of NOx at 20% EGR

9.2 Light Duty Vehicles - Gasoline

9.2.1 Population Projections

The total population of passenger cars and light trucks was obtained from Statistics Canada for the four years 1984 to 1987. Linear regression was used to extrapolate for the total populations for 1988 to 2002.

For passenger cars alone, the number of model year cars for 1984 to 1987 was obtained from the Registrant/Plate/Vehicle Population Statistics as of December 31, 1987 produced by the Ontario Ministry of Transportation.[1] The number of model year cars was the total registered vehicles per model year minus the number of out-of-province vehicles. Again a linear regression was used to provide population estimates for 1988 to 2000.

For light duty trucks, the number of model year vehicles was again obtained from the Registrant/Plate/Vehicle Population Statistics.[1] In this case, the number of vans and light trucks in the commercial vehicle class was used for the years 1984 to 1987. The fraction of passenger vehicles (3%) that were trucks and vans was ignored. Again a linear regression provided the population statistics for 1988 to 2000.

The total and model year populations of passenger cars and light duty trucks are listed in Tables 9.3 and 9.4. These estimates were provided previously in 2.1.

9.2.2 Manufacturing versus Retail Costs

Components of the retail price for motor vehicles have been studied by the EPA and were reported in the Transport Canada report. As shown in Table 9.5, about 60% of the retail price of a passenger car is the manufacturer's cost. The other 40% is due to manufacturer's and dealer's markups, federal sales tax, and research and development expenses [20].

TABLE 9.3 .

PROJECTED COSTS OF POLLUTION CONTROL EQUIPMENT FOR GASOLINE PASSENGER CARS

Model Year	Total Population (000's)	Number of Model Year Cars	Number with New Emission Equipment	Manufacturer Cost ($m - 1987 $ Can)	Retail Cost ($m - 1987 $ Can)		
					Case A	Case B	Case B
	Passenger Cars - Gasoline			($184/vehicle)	($313/vehicle)	($413/vehicle) NOx Control	($593/vehicle CO and HC Contr
1984	3,453	433,603					
1985	3,609	476,189					
1986	3,735	526,503					
1987	3,917	453,263					
1988	4,058	499,713	424,756	78	133	133	133
1989	4,210	510,642	434,046	80	136	136	136
1990	4,362	521,572	443,336	82	139	191 *	139
1991	4,513	532,501	452,626	83	142	195 *	291 *
1992	4,665	543,431	461,916	85	145	199 *	297 *
1993	4,817	554,360	471,206	87	147	203 *	303 *
1994	4,969	565,289	480,496	89	150	207 *	309 *
1995	5,121	576,219	489,786	90	153	211 *	315 *
1996	5,272	587,148	499,076	92	156	215 *	321 *
1997	5,424	598,078	508,366	94	159	219 *	327 *
1998	5,576	609,007	517,656	95	162	223 *	333 *
1999	5,728	619,936	526,946	97	165	227 *	339 *
2000	5,880	630,866	536,236	99	168	231 *	344 *
2001	6,031	641,795	545,526	101	171	235 *	350 *
2002	6,183	652,725	554,816	102	174	239 *	356 *

Note: *: The additional $100 per vehicle became effective in 1990 for additional NOx control. The additional $280 per vehicle became effective in 1991 for additional hydrocarbon and carbon monoxide control.

Case A: 1987 emission standards implemented.

Case B: future control options implemented for NOx, CO, and hydrocarbon control.

TABLE 9.4

PROJECTED COSTS OF POLLUTION CONTROL EQUIPMENT FOR GASOLINE LIGHT DUTY TRUCKS

Model Year	Total Population (000's)	Number of Model Year Trucks	Number with New Emission Equipment	Retail Cost ($m - 1987 $ Can)		
	Light Duty Trucks - Gasoline			Case A ($248/vehicle)	Case B ($348/vehicle) NOx Control	Case B ($528/vehicle) CO and HC Control
1984	539	72,552				
1985	643	72,107				
1986	688	83,747				
1987	691	83,133				
1988	765	88,730	78,082	19	19	19
1989	816	93,068	81,900	20	20	20
1990	866	97,406	85,718	21	31 *	21
1991	916	101,744	89,535	22	32 *	51 *
1992	966	106,083	93,353	23	34 *	53 *
1993	1,016	110,421	97,170	24	35 *	55 *
1994	1,066	114,759	100,988	25	37 *	57 *
1995	1,116	119,097	104,805	26	38 *	59 *
1996	1,166	123,435	108,623	27	39 *	62 *
1997	1,216	127,773	112,440	28	41 *	64 *
1998	1,267	132,111	116,258	29	42 *	66 *
1999	1,317	136,449	120,075	30	43 *	68 *
2000	1,367	140,787	123,893	31	45 *	70 *
2001	1,417	145,126	127,711	32	46 *	72 *
2002	1,467	149,464	131,528	33	48 *	74 *

Note: *: The additional $100 per vehicle became effective in 1990 for additional NOx control. The additional $280 per vehicle became effective in 1991 for additional hydrocarbon and carbon monoxide control.

Case A: 1987 emission standards implemented.

Case B: future control options implemented for NOx, CO, and hydrocarbon control.

TABLE 9.5

RETAIL PRICE COMPONENTS [20]

Component	Percentage of Total Retail Cost
Plant manufacturing cost	
- materials	31.4
- labour	9.6
- plant overhead	3.8
Sub-total:	44.8
Component vendor markup	10.3
Tooling expense	2.9
Assembly, engine and body modifications	2.0
Total vehicle manufacturers' cost:	60.0
Vehicle manufacturer markup	13.8
Federal sales tax	6.6
Dealer markup	13.8
Standard R&D contribution	5.8
Total:	100.0

9.2.3 Vehicle Costs

For passenger cars and light duty trucks, three cases were considered when the costs to control NO_x, CO, and hydrocarbon emissions were analyzed. Case A modelled the effect of the 1987 standards on the pollution control systems required and the resulting annual emission levels of the pollutant. Case B modelled the effect of one possible future control option. In this case, the emission reduction and control equipment cost were estimated based on present emission rates and costs. Case C was the base case in which the 1987 standards were never implemented so that no additional control equipment was required. This option was assumed to have no associated cost.

9.2.3.1 Nitrogen Oxides (NO_x)

For passenger cars in Case A, it was estimated that, for 1988 model year cars and future vehicles, 85% of the model year cars would need an added three-way catalytic converter to meet the 1987 standard for NO_x emissions [20]. Based on estimates from various sources, about 15% of the model year cars were found to have a three-way converter already in place. These 15% were therefore not included in the cost projections for the pollution control devices.

From the Transport Canada analysis of the effect of the 1987 emission standards on light duty vehicles, values for the manufacturer and retail costs of $170 and $289 per vehicle was obtained in 1985 Canadian dollars [20]. To obtain the values in 1987 Canadian dollars, the all-item consumer price index, calculated by Statistics Canada, for 1985 (129.5) and 1987 (140.4) was used. These costs were then $184 and $313 respectively. The ratio of manufacturing to retail cost was 0.59 which substantiated the ratio of 0.6 calculated by the EPA as shown earlier.

For Case B, an extra cost of $100 (1987 $ Can) per catalytic converter was added to the retail cost of the passenger cars and light duty trucks starting in 1990. This extra cost was for additional rhodium required in the converter to meet a NO_x emission standard of 0.4 g/mile. This cost

would be applied to all passenger cars and light duty trucks. For passenger cars, 85% would then have a retail cost of $414 ($313 + $100) per vehicle in 1990 onwards while the other 15% would have an added catalyst cost of only $100.

From the Transport Canada analysis, 88% of the model year light duty trucks were found to require additional pollution control equipment at a retail cost of $248 per vehicle for Case A [20]. For Case B, the cost for these 88% of the light duty trucks would be $348 ($248 + $100) per vehicle to account for the added rhodium. For the other 12%, an added cost of $100 per vehicle would be included in the analysis.

9.2.3.2 Hydrocarbons and Carbon Monoxide (CO)

As for the NO_x emissions case considered above, Case A assumed that 1988 model year cars and future vehicles would all use the three-way catalyst system. Consequently, 85% of the model year vehicles would need to add a three-way catalytic converter at a cost of $313 per vehicle (1987 $ Can).

For Case B, it was assumed that additional CO and hydrocarbon control would be obtained by adding on an early fuel evaporation system (preheater) and a warmup catalytic converter. Both of these would only operate during the first three to five minutes of vehicle use while the car or truck was warming up. Their function would be to reduce hydrocarbon and CO emissions during the time when the main catalytic converter was not yet at its optimum operating temperature.

For this combined preheater and warmup catalyst system, the additional equipment cost was estimated to be $280 (1987 $ Can). These devices would be added to all of the vehicles in 1991. The total equipment cost per vehicle effective in 1991 would then be $528 (1987 $ Can).

The annual capital costs for Case A and Case B for passenger cars and light

duty trucks are also given in Tables 9.2 and 9.4. These are the costs of the various options for the control of NO_x, CO, and hydrocarbons.

9.2.4 Operating Costs

The addition of catalytic converters to light duty gasoline passenger cars and trucks should have a negligible effect on the fuel consumption. Engine modifications and addition of electronic controls have previously been able to limit any increases in the fuel consumption. Further modifications and expansion of the electronic engine controls should still be possible.[20]

Maintenance costs should also be unaffected. The use of stainless steel components in the exhaust system would increase its durability, while the use of unleaded fuels would result in reduced engine and exhaust system corrosion and spark plug wear. The net result would be decreased maintenance costs. However, the increased complexity of the engine computer controls may reduce these benefits due to increased maintenance complexity [20].

9.2.5 Projected Emission Reductions

9.2.5.1 NO_x

To find the NO_x emission reductions due to the different control options adopted, the projected NO_x emissions for the three cases were calculated. For Case A, three-way catalytic converters were in place on all passenger cars and light duty trucks; they reduced the NO_x emissions by 80% compared to an uncontrolled vehicle. This modelled the effect of the standards adopted in 1987.

For Case B, three-way catalytic converters were in place in all vehicles starting with the 1987 model year vehicles as for Case A. In 1990, extra rhodium would be added to reduce the NO_x emission rate to an average of 0.4

g/mile.

For Case C, the catalytic converters were in place in only 15% of the vehicles in the future. This case modelled the effect of not implementing the 1987 emission standards for NO_x.
The reduction in NO_x emissions compared with the base case C was then the difference in emission levels predicted by these Case A and Case B and that of Case C. The projected NO_x emission reductions for Case A and Case B are given in Table 9.6.

9.2.5.2 **Hydrocarbons and Carbon Monoxide (CO)**

For hydrocarbons and CO, Case A again modelled the effect of the 1987 standards. Prior to 1988, 15% of the vehicles would not have any catalytic control. These vehicles would then have reduced CO and hydrocarbon emission rates (90% for CO and hydrocarbons) when the three-way catalytic converters were added. Upgrading any cars with oxidation catalytic systems to the three-way catalytic system would only have a negligible effect on hydrocarbon and CO emission rates.

In the second case, Case B, it was assumed that the early fuel evaporation system and the warmup catalytic converter were in place on 100% of the cars starting with the 1991 model year. An average emissions rate of CO and hydrocarbons in g/mile for the vehicles was then required.

It was calculated that the average trip length was 25 minutes [40]; the car would be warming up for 5 minutes of this time. As well, the CO and hydrocarbon emissions were estimated to be 1.5 times higher during warmup than during later vehicle operation. These warmup emissions were then reduced 30% by the preheater and 45% by the catalytic converter [38]. Adjusted average CO and hydrocarbon emission rates could then be calculated.

TABLE 9.6

PROJECTED EMISSIONS REDUCTION FOR NOx FROM LIGHT DUTY GASOLINE VEHICLES

Year	Projected NOx Emissions Case A (tonne/year)	Case B (tonne/year)	Case C (tonne/year)	NOx Reduction (tonne/year) Case C-A	Case C-B
1984	131,947	131,947	131,947	0	0
1985	142,373	142,373	142,373	0	0
1986	148,607	148,607	148,607	0	0
1987	154,138	154,138	154,138	0	0
1988	144,847	144,847	162,455	17,607	17,607
1989	127,675	127,675	169,759	42,084	42,084
1990	115,276	113,281	177,037	61,761	63,756
1991	102,760	97,947	184,315	81,555	86,369
1992	91,873	83,170	191,593	99,720	108,424
1993	85,728	72,140	198,871	113,143	126,731
1994	80,915	62,047	206,149	125,234	144,102
1995	77,474	54,324	213,427	135,953	159,103
1996	75,951	48,595	220,705	144,754	172,110
1997	71,302	39,999	227,983	156,681	187,984
1998	73,589	39,048	235,288	161,699	196,240
1999	74,264	36,049	242,566	168,301	206,517
2000	78,146	37,130	249,844	171,697	212,714
2001	80,425	38,211	257,122	176,697	218,911
2002	82,704	39,292	264,400	181,696	225,108

Case A: Predictions are based on the assumption that the three-way catalytic converters (used on 100% of the new cars) decrease the NOx emissions by 80%.

Case B: Predictions are the same as for Case A until 1990 when an average NOx emission rate of 0.4 g/mile is achieved.

Case C: Predictions are based on the assumption that the NOx emission standards remain unchanged from the pre-1988 levels.

The third case, Case C, was the base case in which the 1987 standards were never implemented. In this case, oxidation and three-way catalytic converters to control hydrocarbons and CO were in place on only 85% of the vehicles.

The emission reduction for hydrocarbons and CO for the first Case A and Case B was then the difference between their respective annual emission levels and the base case. These reductions in hydrocarbon and CO emission levels are given in Tables 9.7 and 9.8.

9.2.6 Projected Costs of Emission Reductions

9.2.6.1 NO_x

For Case A and Case B, the projected total annual retail cost was the sum of the total retail costs for the passenger cars and the light duty trucks. An analysis period of fourteen years, 1988 to 2002, was chosen. In twelve years, the fleet is assumed to undergo complete renewal so that in the year 2002 the last of the 1991 vehicles in the Case B fleet would be retired. In this analysis, the present value of the costs was used; it was calculated using a 10% discount rate and 1987 as the base year. The total present value over the fourteen year period was $1209 million for Case A and $1569 million for Case B (1987 $ Can).

To determine present values, each model year vehicle costs were multiplied by the factor 1/(1+r)^(i - 1987.5) where r was the discount rate of 10% and i was the model year. The model year vehicle costs were split equally betwen the model year and the previous calendar year [20].

To determine the cost of the NO_x emission reductions in Case A, two options were considered. In the first instance, it was assumed that the cost of the pollution control device was distributed evenly between the NO_x, CO, and hydrocarbon control. One-third of the present value of total cost of the added pollution control equipment was divided by the total predicted NO_x

TABLE 9.7

PROJECTED EMISSIONS REDUCTION FOR HYDROCARBONS FROM LIGHT DUTY GASOLINE VEHICLES

Year	Projected Hydrocarbon Emissions Case A (tonne/year)	Case B (tonne/year)	Case C (tonne/year)	Hydrocarbon Reduction (tonne/year) Case A-C	Case B-C
1984	87,802	87,802	87,802	0	0
1985	94,775	94,775	94,775	0	0
1986	98,936	98,936	98,936	0	0
1987	102,604	102,604	102,604	0	0
1988	99,615	99,615	112,106	12,491	12,491
1989	97,868	97,868	113,034	15,166	15,166
1990	95,366	94,170	117,890	22,524	23,720
1991	92,225	89,884	122,744	30,519	32,860
1992	89,232	85,319	127,598	38,367	42,279
1993	88,015	82,233	132,454	44,439	50,221
1994	87,165	79,432	137,308	50,143	57,876
1995	86,806	77,466	142,163	55,356	64,697
1996	87,357	76,468	147,018	59,661	70,550
1997	85,886	73,544	151,872	65,986	78,328
1998	88,644	75,107	156,745	68,101	81,638
1999	91,370	75,952	158,206	66,837	82,254
2000	94,117	78,235	166,455	72,338	88,220
2001	96,863	80,518	171,309	74,446	90,791
2002	99,610	82,802	176,164	76,554	93,363

Case A: Predictions are based on the the 1987 standards; the main change is in the use of catalytic converters in 15% of the cars which had no previous catalytic control.

Case B: Predictions are based on the assumption that the early fuel evaporation system and the warm-up catalytic converter are in place on 100% of the cars as of the 1991-1992 model year.

Case C: Predictions are based on the assumption that the hydrocarbon emission levels remain unchanged from the pre-1987 levels.

TABLE 9.8

PROJECTED EMISSIONS REDUCTION FOR CO FROM LIGHT DUTY GASOLINE VEHICLES

Year	Projected CO Emissions Case A (tonne/year)	Case B (tonne/year)	Case C (tonne/year)	CO Reduction (tonne/year) Case A-C	Case B-C
1984	1,039,744	1,039,744	1,039,744	0	0
1985	1,122,611	1,122,611	1,122,611	0	0
1986	1,171,967	1,171,967	1,171,967	0	0
1987	1,215,319	1,215,319	1,215,319	0	0
1988	1,219,662	1,219,662	1,327,913	108,252	108,252
1989	1,202,669	1,202,669	1,339,127	136,458	136,458
1990	1,163,256	1,154,879	1,396,713	233,458	241,835
1991	1,103,195	1,084,621	1,454,300	351,105	369,679
1992	1,036,231	1,003,393	1,511,886	475,654	508,493
1993	993,416	942,429	1,569,472	576,056	627,043
1994	953,025	882,348	1,627,058	674,033	744,710
1995	918,889	832,143	1,684,644	765,755	852,501
1996	900,833	798,282	1,742,230	841,397	943,948
1997	913,120	795,674	1,799,816	886,697	1,004,143
1998	942,309	812,646	1,857,623	915,314	1,044,978
1999	971,411	834,664	1,872,615	901,203	1,037,950
2000	1,000,514	859,636	1,972,796	972,282	1,113,160
2001	1,029,616	884,607	2,030,382	1,000,766	1,145,775
2002	1,058,719	909,578	2,087,968	1,029,249	1,178,390

Case A: Predictions are based on the the 1987 standards; the main change is in the use of catalytic converters in 15% of the cars which had no previous catalytic control.

Case B: Predictions are based on the assumption that the early fuel evaporation system and the warm-up catalytic converter are in place on 100% of the cars as of the 1991-1992 model year.

Case C: Predictions are based on the assumption that the CO emission levels remain unchanged from the pre-1987 levels.

emission reductions to get a value in dollars per tonne of NO_x reduction. This value was $305 (1987 $ Can) per tonne of NO_x reduced for Case A.

In the second case, it was assumed that the 75% of the cost of the pollution control systems could be attributed to NO_x reduction. The present value was multiplied by 0.75 and divided by the total predicted NO_x emission reductions to get a value of $693 (1987 $ Can) per tonne of NO_x reduced for Case A. In these two options, the effect of the control equipment on the NO_x is, in turn, minimized or maximized.

In Case B, all of the additional retail cost of $360 million is attributed to NO_x control, as this was the only emission parameter affected (ie. the rhodium catalyst is used to bring NO_x emission below the 0.4 g/VMT level). Adding this to the 75% or 33% of the cost of Case A gives the total cost for NO_x control for Case B. This cost of NO_x control is $838 or $505 per tonne of NO_x removed (1987 $ Can) respectively.

The marginal cost of the additional NO_x control obtained in Case B compared to Case A was $1777 per tonne of NO_x removed. These costs are outlined in Table 9.9.

9.2.6.2 Hydrocarbons and Carbon Monoxide (CO)

For Case A and Case B, in the period 1988 to 2002, the total present value of the cost to control hydrocarbons and CO for Case A and Case B were estimated to be $1209 million (1987 $ Can) and $2217 million (1987 $ Can) respectively.

For both hydrocarbons and CO, two cases were considered. Either 33-1/3% or 12.5% of the cost could be attributed to their control in Case A. This is a result of the two cases considered previously for NO_x control. In the first, 33-1/3% of the cost was attributed to NO_x control. In the second, 50% of the cost was for NO_x control so that 12.5% of the cost was due to hydrocarbon and CO control each. For CO, the cost for CO reduction was $58 per tonne of

TABLE 9.9

PROJECTED COSTS OF NOx EMISSION REDUCTIONS FOR LIGHT DUTY GASOLINE VEHICLES

Year	Total Retail Cost ($m - 1987 $ Can)		Present Value Total Retail Cost ($m - 1987 $ Can)		NOx Emission Reduction (tonne/year)		Present Value Cost of NOx Emission Reduction ($/tonne) (10% discount)	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
1988	152	152	145	145	17,607	17,607	8248	8248
1989	156	156	135	135	42,084	42,084	3217	3217
1990	160	222	126	175	61,761	63,756	2042	2743
1991	164	227	117	163	81,555	86,369	1439	1885
1992	168	233	109	152	99,720	108,424	1095	1398
1993	172	238	102	141	113,143	126,731	898	1112
1994	175	243	94	131	125,234	144,102	754	909
1995	179	249	88	122	135,953	159,103	645	765
1996	183	254	81	113	144,754	172,110	563	657
1997	187	260	76	105	156,681	187,984	483	558
1998	191	265	70	97	161,699	196,240	434	496
1999	195	270	65	90	168,301	206,517	387	437
2000	199	276	60	84	171,697	212,714	351	394
2001	202	281	56	78	176,697	218,911	316	355
2002	206	286	52	72	181,696	225,108	285	320
		Totals:	$1,209	$1,569	1,308,493	1,511,027		

Case A:

Total Retail Cost:	$1,209	$m - 1987 $ Can
Total NOx Reduction:	1,308,493	tonnes NOx
Cost of NOx Reduction:		
i. 75% of total cost:	$693	1987 $ Can per tonne NOx
ii. 33% of total cost:	$305	1987 $ Can per tonne NOx

Case B:

Total Retail Cost:	$1,569	$m - 1987 $ Can
Additional Retail Cost:	$360	$m - 1987 $ Can
Total NOx Reduction:	1,511,027	tonnes NOx
Cost of NOx Reduction:		
i. 75% of Case A cost:	$838	1987 $ Can per tonne NOx
ii. 33% of Case A cost:	$505	1987 $ Can per tonne NOx

Marginal Cost of Additional NOx Control:

Case A - Case B:

Retail Cost Difference:	$360	$m - 1987 $ Can
NOx Reduction Difference:	202,534	tonnes NOx
Marginal Cost:	$1,777	1987 $ Can per tonne NOx

Case A: 1987 standard for NOx in effect.

Case B: Additional control for NOx was achieved by using additional rhodium in the three-way catalytic converter.

CO removed or $22 per tonne of CO removed. The cost for hydrocarbons was $754 per tonne or $285 per tonne of hydrocarbons reduced depending on the fraction of control cost which is attributed to hydrocarbon and CO control.

For Case B, the cost could be divided equally between CO and hydrocarbon control since the warmup catalyst and preheater only affected these emissions. For CO and hydrocarbons, 50% of the additional retail cost, $1008 million (1987 $ Can) would then be added to 33% or 12.5% of the cost in Case A in order to calculate the cost of CO and hydrocarbon control. For CO, $119 or $86 per tonne would be spent on CO control compared with $1475 or $1070 per tonne for hydrocarbon control.

The marginal cost of additional CO control was $709 per tonne CO removed or $940 per tonne of CO removed depending on whether 12.5% or 33-1/3% of the total cost in Case A was assigned to CO control. For hydrocarbon control, this marginal cost was $614 per tonne or $11606 per tonne of hydrocarbon reduction again depending on whether 12.5% or 33-1/3% of the total cost in Case A was assigned to hydrocarbon control. These costs for CO and hydrocarbon control are tabulated in Tables 9.10 and 9.11 respectively.

TABLE 9.10

PROJECTED COSTS OF HYDROCARBON EMISSION REDUCTIONS FROM LIGHT DUTY GASOLINE VEHICLES

Year	Total Retail Cost ($m - 1987)		Present Value Total Retail Cost ($m - 1987 $ Can)		Hydrocarbon Emission Reduction (tonne/year)		Present Value of Cost of Hydrocarbon Emission Reduction ($/tonne)(10% discount)	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
1988	152	152	145	145	12,491	12,491	11,626	11,626
1989	156	156	135	135	15,166	15,166	8,925	8,925
1990	160	333	126	263	22,524	23,720	5,598	11,073
1991	164	341	117	245	30,519	32,860	3,847	7,444
1992	168	350	109	228	38,367	42,279	2,847	5,385
1993	172	358	102	212	44,439	50,221	2,286	4,217
1994	175	366	94	197	50,143	57,876	1,883	3,402
1995	179	374	88	183	55,356	64,697	1,585	2,828
1996	183	382	81	170	59,661	70,550	1,365	2,409
1997	187	390	76	158	65,986	78,328	1,146	2,015
1998	191	398	70	146	68,101	81,638	1,030	1,794
1999	195	407	65	136	66,837	82,254	974	1,652
2000	199	415	60	126	72,338	88,220	834	1,428
2001	202	423	56	117	74,446	90,791	751	1,286
2002	206	431	52	108	76,554	93,363	677	1,159
		Totals:	$1,209	$2,217	529,591	612,081		

Case A:

Total Retail Cost:	$1,209	$m - 1987 $ Can
Total Hydrocarbon Reduction:	529,591	tonnes hydrocarbons
Cost of Hydrocarbon Reduction:		
i. 33% of total cost:	$754	1987 $ Can per tonne hydrocarbons
i. 12.5% of total cost:	$285	1987 $ Can per tonne hydrocarbons

Case B:

Total Retail Cost:	$2,217	$m - 1987 $ Can
Total Hydrocarbon Reduction:	612,081	tonnes hydrocarbons
Additional Retail Cost:	$1,008	$m - 1987 $ Can
Cost of Hydrocarbon Reduction:		
i. 33% of Case A cost:	$1,475	1987 $ Can per tonne hydrocarbons
ii. 12.5% of Case A cost:	$1,070	1987 $ Can per tonne hydrocarbons

Marginal Cost of Additional Hydrocarbon Control:

Case A - Case B:

Retail Cost Difference:	$1,008	$m - 1987 $ Can
Hydrocarbon Reduction Difference:	82,489	tonnes hydrocarbons
Marginal Cost:	$6,109	1987 $ Can per tonne hydrocarbons

Case A: 1987 standards for hydrocarbons and CO in effect.

Case B: Additional CO and hydrocarbon control was achieved through the use of an early fuel evaporation system and a warm-up catalytic converter.

TABLE 9.11

PROJECTED COSTS OF CO EMISSION REDUCTIONS FOR LIGHT DUTY GASOLINE VEHICLES

Year	Total Retail Cost ($m - 1987)		Present Value Total Retail Cost ($m - 1987 $ Can)		CO Emission Reduction (tonne/year)		Present Value of Cost of CO Emission Reduction ($/tonne)(10% discount)	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
1988	152	152	145	145	108,252	108,252	1342	1342
1989	156	156	135	135	136,458	136,458	992	992
1990	160	333	126	263	233,458	241,835	540	1086
1991	164	341	117	245	351,105	369,679	334	662
1992	168	350	109	228	475,654	508,493	230	448
1993	172	358	102	212	576,056	627,043	176	338
1994	175	366	94	197	674,033	744,710	140	264
1995	179	374	88	183	765,755	852,501	115	215
1996	183	382	81	170	841,397	943,948	97	180
1997	187	390	76	158	886,697	1,004,143	85	157
1998	191	398	70	146	915,314	1;044,978	77	140
1999	195	407	65	136	901,203	1,037,950	72	131
2000	199	415	60	126	972,282	1,113,160	62	113
2001	202	423	56	117	1,000,766	1,145,775	56	102
2002	206	431	52	108	1,029,249	1,178,390	50	92
		Totals	$1,209	$2,217	6,865,382	7,619,990		

Case A:
Total Retail Cost: $1,209 $m - 1987 $ Can
Total CO Reduction: 6,865,382 tonnes CO
Cost of CO Reduction:
i. 33% of total cost: $58 1987 $ Can per tonne CO
i. 12.5% of total cost: $22 1987 $ Can per tonne CO

Case B:
Total Retail Cost: $2,217 $m - 1987 $ Can
Additional Retail Cost: $1,008 $m - 1987 $ Can
Total CO Reduction: 7,619,990 tonnes CO
Cost of CO Reduction:
i. 33% of Case A cost: $119 1987 $ Can per tonne CO
ii. 12.5% of Case A cost $86 1987 $ Can per tonne CO

Marginal Cost of Additional CO Control:
Case A - Case B:
Retail Cost Difference: $1,008 $m - 1987 $ Can
CO Reduction Difference: 754,608 tonnes CO
Marginal Cost: $668 1987 $ Can per tonne CO

Case A: 1987 standards for hydrocarbons, CO, and NOx in effect.
Case B: Additional CO and hydrocarbon control was achieved through the use of an early fuel evaporation system and a warm-up catalytic converter.

9.3 Light Duty Vehicles - Diesel

9.3.1 Population Projections

Light duty diesel vehicles accounted for 1.5% of all new car sales and 6.5% of all new light duty truck sales reported in the Transport Canada report [20]. For 1984 to 1987, the total and model year diesel car populations were found by multiplying the total and model year passenger year population by 0.015. The assumption was made that the fraction of car sales which were diesel vehicles would remain constant. Linear regression was used to extrapolate for the total and model year diesel passenger car populations for the years 1988 to 2002.

The same procedure was used to predict the total and model year light duty diesel truck populations. The populations for passenger cars and light duty trucks are shown in Tables 9.12 and 9.13.

9.3.2 Vehicle Costs

9.3.2.1 Nitrogen Oxides (NO_x) and Particulates

Two cases were considered for NO_x and particulate control in diesel passenger cars and trucks. In Case A, the cost of the engine modifications required to meet the NO_x and particulate standards implemented in 1987, based on industry estimates, was \$651 per vehicle [20]. The cost for light duty diesel trucks would be \$51 per vehicle [20].

For the second case, Case B, additional particulate control would be gained through the use of particulate traps which would be added to all cars and trucks starting with the 1990 model year. These traps would have no effect on the NO_x emission rate, however. An estimate of the cost of these traps is \$300 per vehicle so that the total equipment cost would be \$950 per car and \$351 per truck.

TABLE 9.12

PROJECTED COSTS OF POLLUTION CONTROL EQUIPMENT

Model Year	Total Population	Number of Model Year Cars	Retail Cost ($m - 1987 $ Can)	
		Passenger Cars - Diesel	Case A ($651/vehicle)	Case B ($950/vehicle)
1984	51,795	6,504		
1985	54,135	7,143		
1986	56,025	7,898		
1987	58,755	6,799		
1988	60,870	7,496	4.9	4.9
1989	63,147	7,660	5.0	5.0
1990	65,424	7,824	5.1	7.4 *
1991	67,701	7,988	5.2	7.6 *
1992	69,978	8,151	5.3	7.7 *
1993	72,255	8,315	5.4	7.9 *
1994	74,532	8,479	5.5	8.1 *
1995	76,809	8,643	5.6	8.2 *
1996	79,086	8,807	5.7	8.4 *
1997	81,363	8,971	5.8	8.5 *
1998	83,640	9,135	5.9	8.7 *
1999	85,917	9,299	6.0	8.8 *
2000	88,194	9,463	6.2	9.0 *
2001	90,471	9,627	6.3	9.2 *
2002	92,748	9,791	6.4	9.3 *

Note: *:The additional $300 per vehicle became effective in 1990.

Case A: 1987 standards for NOx and particulates in effect.

Case B: Additional particulate control was obtained by adding particulate traps.

TABLE 9.13

PROJECTED COSTS OF POLLUTION CONTROL EQUIPMENT

Model Year	Total Population	Number of Model Year Trucks	Retail Cost ($m - 1987 $ Can)	
Light-Duty Trucks - Diesel			Case A ($51/vehicle)	Case B ($351/vehicle)
1984	35,035	4,716		
1985	41,795	4,687		
1986	44,720	5,444		
1987	44,915	5,404		
1988	49,757	5,767	0.29	0.29
1989	53,014	6,049	0.31	0.31
1990	56,271	6,331	0.32	2.22 *
1991	59,527	6,613	0.34	2.32 *
1992	62,784	6,895	0.35	2.42 *
1993	66,040	7,177	0.37	2.52 *
1994	69,297	7,459	0.38	2.62 *
1995	72,553	7,741	0.39	2.72 *
1996	75,810	8,023	0.41	2.82 *
1997	79,066	8,305	0.42	2.91 *
1998	82,323	8,587	0.44	3.01 *
1999	85,579	8,869	0.45	3.11 *
2000	88,836	9,151	0.47	3.21 *
2001	92,092	9,433	0.48	3.31 *
2002	95,349	9,715	0.50	3.41 *

Note: *:The additional $300 per vehicle became effective in 1990.

Case A: 1987 standards for NOx and particulates in effect.

Case B: Additional particulate control was obtained by adding particulate traps.

The total annual retail cost for diesel passenger cars and light duty trucks for Case A and Case B are also listed in Tables 9.12 and 9.13 respectively.

9.3.3 Operating Costs

The effect of the particulate traps on the vehicle maintenance and operating costs has not been quantified. Because of their low sales volume, 1.5% of passenger car sales and 6.5% of light duty truck sales, any cost increases would be negligible in relation to the total costs for all light duty vehicles.

9.3.4 Projected Emissions Reductions

9.3.4.1 Nitrogen Oxides (NO_x) and Particulates

Three scenarios were considered. For Case A, the future predictions were based on the 1987 standards. Engine modifications were used to attain NO_x and particulate control. An average emission rate of 0.12 g/km was used for particulate emissions which is the same as the 1987 standard for particulates.

For Case B, emission level predictions were based on the assumption that effective particulate traps had been developed for light duty diesel vehicles. These traps would have no effect on NO_x emissions so that the emission rate in tonnes/year would be the same for Case A. It was assumed that the particulate traps developed for these vehicles were 80% effective so that the average particulate emission rate was 0.024 g/km.

In Case C, the predictions are based on the assumption that the NO_x and particulate emission levels remain unchanged from pre-1987 levels. The reduction in NO_x and particulate emissions for Case A and Case B relative to the base case, Case C, can then be calculated. The annual NO_x and particulate emission rates for the three cases are listed in Tables 9.14 and

TABLE 9.14

PROJECTED EMISSIONS REDUCTION FOR NOx FROM LIGHT DUTY DIESEL VEHICLES

Year	Projected NOx Emissions Case A (tonne/year)	Case B (tonne/year)	Case C (tonne/year)	NOx Reduction (tonne/year) Case A-C	Case B-C
1984	1,638	1,638	1,638	0	0
1985	1,781	1,781	1,781	0	0
1986	1,806	1,806	1,806	0	0
1987	1,771	1,771	1,771	0	0
1988	1,768	1,768	1,897	129	129
1989	1,759	1,759	1,996	237	237
1990	1,779	1,779	2,094	315	315
1991	1,805	1,805	2,193	388	388
1992	1,849	1,849	2,291	442	442
1993	1,905	1,905	2,390	485	485
1994	1,958	1,958	2,488	530	530
1995	2,018	2,018	2,586	568	568
1996	2,085	2,085	2,684	599	599
1997	2,160	2,160	2,783	623	623
1998	2,236	2,236	2,881	645	645
1999	2,311	2,311	2,980	669	669
2000	2,387	2,387	3,078	691	691
2001	2,462	2,462	3,176	714	714
2002	2,537	2,537	3,274	737	737

Case A: Predictions are based on the the 1987 standards; the main change is in the use of engine controls to attain the NOx and particulate standards.

Case B: Predictions are based on the assumption that particulate traps are developed for light duty diesel vehicles.

Case C: Predictions are based on the assumption that the particulate and NOx emission levels remain unchanged from the pre-1987 levels.

TABLE 9.15

PROJECTED EMISSIONS REDUCTION FOR PARTICULATES FROM LIGHT DUTY DIESEL VEHICLES

Year	Projected Particulate Emissions Case A (tonne/year)	Case B (tonne/year)	Case C (tonne/year)	Particulate Reduction (tonne/year) Case A-C	Case B-C
1984	609	609	609	0	0
1985	673	673	673	0	0
1986	707	707	707	0	0
1987	728	728	728	0	0
1988	664	664	815	151	151
1989	605	605	815	210	210
1990	544	502	854	310	352
1991	482	405	893	411	488
1992	429	316	932	503	616
1993	400	250	971	571	721
1994	377	194	1,009	632	815
1995	361	154	1,048	687	894
1996	355	126	1,087	732	961
1997	367	120	1,126	759	1,006
1998	380	117	1,165	785	1,048
1999	393	121	1,173	780	1,052
2000	405	125	1,242	837	1,117
2001	418	129	1,281	863	1,152
2002	431	132	1,320	889	1,188

Case A: Predictions are based on the the 1987 standards; the main change is in the use of engine controls to attain the NOx and particulate standards.

Case B: Predictions are based on the assumption that particulate traps are developed for light duty diesel vehicles.

Case C: Predictions are based on the assumption that the particulate and NOx emission levels remain unchanged from the pre-1988 levels.

9.15.

9.3.5 Projected Costs of Emission Reductions

9.3.5.1 Nitrogen Oxides (NO_x) and Particulates

The projected retail cost of the pollution control equipment was the sum of the costs for the diesel passenger cars and light duty trucks. Again, a 10% discount rate was used and 1987 was the base year. The total present value over the fourteen year period of 1988 to 2002 was $40.7 million (1987 $ Can) for Case A and $66.0 million (1987 $ Can) for Case B.

For Case A, 50% of the total retail cost could be attributed to NOx control. This resulted in a cost of NO_x reduction of $3618 per tonne of NO_x reduction. The cost of particulate reduction for Case A, if 50% of the cost was due to particulate control, was $3119 per tonne of particulate reduction.

For Case B, all of the additional cost of $46 million (1987 $ Can) is associated with particulate control. Adding this to 50% of the Case A cost yields a cost for the particulate reduction of $5490 per tonne of particulate removed. The cost of NO_x control, $3618 per tonne of NO_x removed, is the same as for Case A. The marginal cost of this additional particulate control was $25,598 per tonne of particulate control.

These costs for NO_x and particulates are tabulated in Tables 9.16 and 9.17, respectively.

9.4 Heavy Duty Vehicles

9.4.1 Population Projections

For heavy duty vehicles, the vehicle population was obtained from the Registrant/Plate/Vehicle Population Statistics.[1] The total population and model year population of gasoline and diesel vehicles in the commercial

TABLE 9.16

PROJECTED COSTS OF NOx EMISSION REDUCTIONS FROM LIGHT DUTY DIESEL VEHICLES

Year	Total Retail Cost ($m - 1987)		Present Value Total Retail Cost ($m - 1987 $ Can)		NOx Emission Reduction (tonne/year)		Present Value of Cost of NOx Emission Reduction ($/tonne)(10% discount)	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
1988	5	5	5	5	129	129	38,211	38,211
1989	5	5	5	5	237	237	19,350	19,350
1990	5	10	4	8	315	315	13,538	24,161
1991	6	10	4	7	388	388	10,215	18,302
1992	6	10	4	7	442	442	8,330	14,981
1993	6	10	3	6	485	485	7,049	12,723
1994	6	11	3	6	530	530	5,987	10,843
1995	6	11	3	5	568	568	5,183	9,417
1996	6	11	3	5	599	599	4,558	8,307
1997	6	11	3	5	623	623	4,062	7,426
1998	6	12	2	4	645	645	3,636	6,666
1999	7	12	2	4	669	669	3,247	5,970
2000	7	12	2	4	691	691	2,911	5,367
2001	7	12	2	3	714	714	2,608	4,820
2002	7	13	2	3	737	737	2,338	4,332
		Totals:	$40.7	$66.0	5,630	5,630		

Case A:

Total Retail Cost:	$40.7	$m - 1987 $ Can
Total NOx Reduction:	5,630	tonnes NOx
Cost of NOx Reduction:		
i. 50% of total cost:	$3,618	1987 $ Can per tonne NOx

Case B:

Total Retail Cost:	$66.0	$m - 1987 $ Can
Total NOx Reduction:	5,630	tonnes NOx
Cost of NOx Reduction:		
i. 50% of Case A cost:	$3,618	1987 $ Can per tonne NOx

Marginal Cost of Additional NOx Control:

Case A - Case B:

Retail Cost Difference (for NOx):	$0	$m - 1987 $ Can
NOx Reduction Difference:	0	tonnes NOx
Marginal Cost:	-----	1987 $ Can per tonne NOx

Case A: 1987 standards for NOx and particulates in effect.

Case B: Additional particulate control is achieved by adding particulate traps to the vehicles.

TABLE 9.17

PROJECTED COSTS OF PARTICULATE EMISSION REDUCTIONS FOR LIGHT DUTY DIESEL VEHICLES

Year	Total Retail Cost ($m - 1987)		Present Value Total Retail Cost ($m - 1987 $ Can)		Particulate Emission Reduction (tonne/year)		Present Value of Cost of Particulate Emission Reduction ($/tonne)(10% discount)	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
1988	5	5	5	5	151	151	32,644	32,644
1989	5	5	5	5	210	210	21,838	21,838
1990	5	10	4	8	310	352	13,756	21,621
1991	6	10	4	7	411	488	9,644	14,552
1992	6	10	4	7	503	616	7,320	10,749
1993	6	10	3	6	571	721	5,988	8,558
1994	6	11	3	6	632	815	5,021	7,051
1995	6	11	3	5	687	894	4,285	5,983
1996	6	11	3	5	732	961	3,730	5,178
1997	6	11	3	5	759	1,006	3,334	4,599
1998	6	12	2	4	785	1,048	2,988	4,103
1999	7	12	2	4	780	1,052	2,785	3,797
2000	7	12	2	4	837	1,117	2,404	3,320
2001	7	12	2	3	863	1,152	2,158	2,987
2002	7	13	2	3	889	1,188	1,939	2,687
		Totals	$40.7	$66.0	6,531	8,314		

Case A:
Total Retail Cost: $40.7 $m - 1987 $ Can
Total Particulate Reduction 6,531 tonnes particulates
Cost of Particulate Reduction:
i. 50% of total cost: $3,119 1987 $ Can per tonne particulates

Case B:
Total Retail Cost: $66.0 $m - 1987 $ Can
Total Particulate Reduction 8,314 tonnes particulates
Cost of Particulate Reduction:
i. 50% of Case A cost: $5,490 1987 $ Can per tonne particulates

Marginal Cost of Additional Particulate Control:
Case A - Case B:
Retail Cost Difference: $46 $m - 1987 $ Can
Particulate Reduction Difference: 1,783 tonnes particulates
Marginal Cost: $25,598 1987 $ Can per tonne particulates

Case A: 1987 standards for particulates and NOx in effect.
Case B: Additional particulate control is achieved by adding particulate traps to the vehicles.

vehicle category was used for the years 1984 to 1987. Linear regression was used to estimate the populations for 1988 to 2002.

From an analysis of heavy duty vehicle sales in the Transport Canada analysis [4], the percentage of the model year vehicles in 1988 which were gasoline was estimated to be 41.6%. The percentage of the heavy duty vehicles which were diesel was then 58.2%. Using these percentages, the total and model year populations of gasoline and diesel vehicles were calculated.

The total and model year populations of heavy duty gasoline and diesel vehicles are shown in Tables 9.18 and 9.26.

Light heavy duty gasoline vehicles (HDGV) are classified as those weighing less than 6350 kg gross vehicle weight rating (GVWR), while medium heavy duty gasoline vehicles are those that weigh more than 6350 kg GVWR. Light HDGV comprise about 77% of the HDGV population, while medium HDGV make up the other 23%. Heavy duty diesel vehicles (HDDV) are divided into three weight classes. Light HDDV weigh between 3856 kg and 8845 kg GVWR, medium HDDV weigh between 8846 kg and 14969 kg GVWR, while heavy HDDV weigh more than 14969 kg. The percentage of HDDV which are in the light, medium, and heavy duty vehicle categories are about 30%, 25%, and 45% respectively.

9.5 Heavy Duty Vehicles - Gasoline

9.5.1 Vehicle Costs

Two cases were considered when vehicle costs were studied. Case A modelled the effect of the implementation of the standards for heavy duty vehicles on December 1, 1988. From the Transport Canada report [4], the cost to meet the 1988 standards for NO_x, hydrocarbons, and CO was $170 (1985 $ Can) or $184 (1987 $ Can).

In Case B, a future option, it was assumed that catalytic converters would be available for the 1992 model year vehicles at an additional estimated

TABLE 9.18

PROJECTED COSTS OF POLLUTION CONTROL EQUIPMENT FOR HEAVY DUTY GASOLINE VEHICLES

Model Year	Total Population	Number of Model Year Trucks	Retail Cost ($m - 1987 $ Can)	
	Heavy Duty Vehicles - Gasoline		Case A ($184/vehicle)	Case B ($784/vehicle)
1984	21,085	1,832		
1985	23,223	2,254		
1986	25,639	2,777		
1987	28,264	2,885		
1988	30,541	3,357	0.6	0.6
1989	32,936	3,725	0.7	0.7
1990	35,332	4,093	0.8	0.8
1991	37,727	4,462	0.8	0.8
1992	40,122	4,830	0.9	3.8 *
1993	42,517	5,198	1.0	4.1 *
1994	44,913	5,566	1.0	4.4 *
1995	47,308	5,934	1.1	4.7 *
1996	49,703	6,302	1.2	4.9 *
1997	52,099	6,670	1.2	5.2 *
1998	54,494	7,038	1.3	5.5 *
1999	56,889	7,406	1.4	5.8 *
2000	59,284	7,774	1.4	6.1 *
2001	61,680	8,143	1.5	6.4 *
2002	64,075	8,511	1.6	6.7 *

Note: *:The additional $600 per vehicle became effective in 1992.

Case A: 1988 standards in effect for CO, hydrocarbons, and NOx.
Case B: Additional control of CO, hydrocarbons, and NOx is gained by using catalytic converters.

cost of $600 per vehicle for a total cost of $784 per vehicle (1987 $ Can).

The total annual retail cost for Case A and Case B for heavy duty gasoline vehicles was given in Table 9.18.

9.5.2 Operating Costs

For Case A, no changes in operating costs are expected as a result of any engine modifications [4]. For Case B, it was assumed that the catalytic converter would have to be regenerated every 50,000 km at a cost of $100. Since the total distance travelled by a HDGV in its lifetime is about 177,300 km [4], the catalyst would have to be regenerated three times during the vehicle's lifetime. No changes in the fuel consumption were available for inclusion in the analysis.

For each HDGV in Case B, the present value of the total lifetime cost for regeneration over its 20 year operating life would be $145 (1987 $ Can) discounted using a 10% discount rate. For the model years 1988 to 2002 used in the analysis, the present value of the total lifetime maintenance costs would be $12,930,000. These operating costs are given in Table 9.19.

9.5.3 Projected Emissions Reductions

Emission rates of hydrocarbons, CO, and NO_x for heavy duty gasoline vehicles over the lifetime of the vehicles were obtained from the Transport Canada report [4] for two cases. In Case A, the emission rates were based on the adoption of the 1988 standards, and, in the second, Case C, the standards were not implemented. The NO_x, hydrocarbon, and CO emission rates were then unchanged from pre-1987 levels.

For the future scenario considered, Case B, it is assumed that a catalytic converter has been developed which is 80% efficient in reducing the hydrocarbon and CO emissions and 70% efficient in reducing the NO_x

TABLE 9.19

OPERATING COSTS OF HEAVY DUTY GASOLINE VEHICLES

Case B

Model Year	Population	Vehicle Population LHDGV	MHDGV	Total Lifetime Cost (1987 $ Can) (10% discount)
1988	3,357	2,585	772	487,708
1989	3,725	2,869	857	541,183
1990	4,093	3,152	941	594,657
1991	4,462	3,435	1,026	648,132
1992	4,830	3,719	1,111	701,606
1993	5,198	4,002	1,195	755,081
1994	5,566	4,286	1,280	808,556
1995	5,934	4,569	1,365	862,030
1996	6,302	4,853	1,449	915,505
1997	6,670	5,136	1,534	968,980
1998	7,038	5,419	1,619	1,022,454
1999	7,406	5,703	1,703	1,075,929
2000	7,774	5,986	1,788	1,129,404
2001	8,143	6,270	1,873	1,182,878
2002	8,511	6,553	1,957	1,236,353
				$12,930,456

Case B: Additional hydrocarbon, CO, and NOx control is achieved through the development of catalytic converters for heavy duty gasoline vehicles.

emissions. Because catalytic converters for heavy duty gasoline vehicles are currently not available because of technical problems, this future scenario may not be feasible by the year 1992.

The projected emissions for NO_x, CO, and hydrocarbons for the three cases are given in Tables 9.20, 9.21, and 9.21.

9.5.4 Projected Costs of Emission Reductions

For heavy duty gasoline vehicles, the present value of the total retail cost over the years 1988 to 2002 was $6.5 million for Case A and $20.2 million for Case B. For both Case A and Case B, it was assumed that the cost for control could be attributed equally to CO, NO_x, and hydrocarbon control.

In Case A, this resulted in a cost for control of $77 per tonne CO, $149 per tonne hydrocarbon, and $4021 per tonne NO_x removed. In Case B, this cost was $160 per tonne Co, $393 per tonne hydrocarbon, and $3444 per tonne NO_x. The marginal cost of the additional control was $327 per tonne Co, $1874 per tonne hydrocarbon, and $3222 per tonne NO_x.

These costs are tabulated in Tables 9.23 and 9.25.

9.6 Heavy Duty Vehicles - Diesel

9.6.1 Vehicle Costs

The two cases used with the heavy duty gasoline vehicles were again considered for costing of the heavy duty diesel vehicles. The first, Case a, again modelled the 1988 standards for HDDV. From the Transport Canada report [4], the cost to meet the NO_x and particulate standards was $560 (1985 $ Can) or $607 (1987 $ Can).

For Case B, a possible future scenario, it was assumed that particulate

TABLE 9.20

PROJECTED EMISSIONS REDUCTION FOR NOx FROM HEAVY DUTY GASOLINE VEHICLES

Year	Projected NOx Emissions Case A (tonne/year)	Case B (tonne/year)	Case C (tonne/year)	NOx Reduction (tonne/year) Case A-C	Case B-C
1984	2,402	2,402	2,402	0	0
1985	2,645	2,645	2,645	0	0
1986	2,920	2,920	2,920	0	0
1987	3,219	3,219	3,219	0	0
1988	3,479	3,479	3,479	0	0
1989	3,735	3,735	3,752	17	17
1990	3,989	3,989	4,025	36	36
1991	4,241	4,241	4,297	56	56
1992	4,493	4,360	4,570	77	210
1993	4,745	4,471	4,843	98	372
1994	4,997	4,573	5,116	119	543
1995	5,249	4,672	5,389	140	717
1996	5,502	4,772	5,662	160	890
1997	5,757	4,878	5,934	177	1,056
1998	5,988	4,965	6,207	219	1,242
1999	6,251	5,092	6,480	229	1,388
2000	6,514	5,229	6,753	239	1,524
2001	6,777	5,199	7,026	249	1,827
2002	7,041	5,401	7,299	258	1,898

Case A: Predictions are based on the the 1988 standards; the main change is in the use of engine controls to attain the NOx, hydrocarbon, and CO emission standards.

Case B: Predictions are based on the assumption that catalytic converters are developed for heavy duty gasoline vehicles.

Case C: Predictions are based on the assumption that the NOx, HC, and CO emission levels remain unchanged from the pre-1989 levels.

TABLE 9.21

PROJECTED EMISSIONS REDUCTION FOR HYDROCARBONS FROM HEAVY DUTY GASOLINE VEHICLES

Year	Projected Hydrocarbon Emissions Case A (tonne/year)	Case B (tonne/year)	Case C (tonne/year)	Hydrocarbon Reduction (tonne/year) Case A-C	Case B-C
1984	3,888	3,888	3,888	0	0
1985	4,282	4,282	4,282	0	0
1986	4,728	4,728	4,728	0	0
1987	5,212	5,212	5,212	0	0
1988	5,631	5,631	5,631	0	0
1989	5,571	5,571	6,073	502	502
1990	5,489	5,489	6,515	1,026	1,026
1991	5,387	5,387	6,956	1,569	1,569
1992	5,282	5,053	7,398	2,116	2,345
1993	5,190	4,719	7,840	2,650	3,121
1994	5,121	4,392	8,282	3,161	3,890
1995	5,075	4,083	8,723	3,648	4,640
1996	5,060	3,804	9,165	4,105	5,361
1997	5,081	3,568	9,607	4,526	6,039
1998	4,626	2,866	10,048	5,422	7,182
1999	4,830	2,835	10,490	5,660	7,655
2000	5,033	2,822	10932	5,899	8,110
2001	5,236	2,520	11,373	6,137	8,853
2002	5,440	2,618	11,815	6,375	9,197

Case A: Predictions are based on the the 1988 standards; the main change is in the use of engine controls to attain the NOx, hydrocarbon, and CO emission standards.

Case B: Predictions are based on the assumption that catalytic converters are developed for heavy duty gasoline vehicles.

Case C: Predictions are based on the assumption that the NOx, HC, and CO emission levels remain unchanged from the pre-1989 levels.

TABLE 9.22

PROJECTED EMISSIONS REDUCTION FOR CO FROM HEAVY DUTY GASOLINE VEHICLES

Year	Projected CO Emissions Case A (tonne/year)	Case B (tonne/year)	Case C (tonne/year)	CO Reduction (tonne/year) Case A-C	Case B-C
1984	15,382	15,382	15,382	0	0
1985	16,942	16,942	16,942	0	0
1986	18,704	18,704	18,704	0	0
1987	20,619	20,619	20,619	0	0
1988	22,280	22,280	22,280	0	0
1989	23,000	23,000	24,028	1,028	1,028
1990	23,713	23,713	25,775	2,062	2,062
1991	24,422	24,422	27,523	3,101	3,101
1992	25,161	23,853	29,270	4,109	5,417
1993	25,967	23,261	31,017	5,050	7,756
1994	26,823	22,654	32,765	5,942	10,111
1995	27,754	22,071	34,512	6,758	12,441
1996	28,753	21,562	36,260	7,507	14,698
1997	29,820	21,161	38,007	8,187	16,846
1998	30,252	20,174	39,755	9,503	19,581
1999	31,582	20,163	41,502	9,920	21,339
2000	32,912	20,255	43,249	10,337	22,994
2001	34,242	18,690	44,997	10,755	26,307
2002	35,571	19,416	46,744	11,173	27,328

Case A: Predictions are based on the the 1988 standards; the main change is in the use of engine controls to attain the NOx, hydrocarbon, and CO emission standards.

Case B: Predictions are based on the assumption that catalytic converters are developed for heavy duty gasoline vehicles.

Case C: Predictions are based on the assumption that the NOx, HC, and CO emission levels remain unchanged from the pre-1989 levels.

TABLE 9.23

PROJECTED COSTS OF NOx EMISSION REDUCTIONS FOR HEAVY DUTY GASOLINE VEHICLES

Year	Total Retail Cost ($m - 1987)		Present Value Total Retail Cost ($m - 1987 $ Can)		NOx Emission Reduction (tonne/year)		Present Value of Cost of NOx Emission Reduction ($/tonne)(10% discount)	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
1988	0.6	0.6	0.6	0.6	0	0	0	0
1989	0.7	0.7	0.6	0.6	0	0	0	0
1990	0.8	0.8	0.6	0.6	0	0	0	0
1991	0.8	0.8	0.6	0.6	0	0	0	0
1992	0.9	3.8	0.6	2.5	0	0	0	0
1993	1.0	4.1	0.6	2.4	17	17	33,362	141,969
1994	1.0	4.4	0.6	2.3	36	36	15,336	65,262
1995	1.1	4.7	0.5	2.3	56	56	9,556	40,663
1996	1.2	4.9	0.5	2.2	77	210	6,710	10,469
1997	1.2	5.2	0.5	2.1	98	372	5,073	5,687
1998	1.3	5.5	0.5	2.0	119	543	4,007	3,737
1999	1.4	5.8	0.5	1.9	140	717	3,258	2,707
2000	1.4	6.1	0.4	1.9	160	890	2,721	2,081
2001	1.5	6.4	0.4	1.8	177	1,056	2,342	1,670
2002	1.6	6.7	0.4	1.7	219	1,242	1,798	1,349
		Totals:	$6.5	$20.2	543	1,951		

Case A:
Total Retail Cost: $6.5 $m - 1987 $ Can
Total NOx Reduction: 543 tonnes NOx
Cost of NOx Reduction:
i. 33% of total cost: $4,021 1987 $ Can per tonne NOx

Case B:
Total Retail Cost: $20.2 $m - 1987 $ Can
Total NOx Reduction: 1,951 tonnes NOx
Cost of NOx Reduction:
i. 33% of total cost: $3,444 1987 $ Can per tonne NOx

Marginal Cost of Additional NOx Control:
Case A - Case B:
Retail Cost Difference: $14 $m - 1987 $ Can
NOx Reduction Difference: 1,408 tonnes NOx
Marginal Cost: $3,222 1987 $ Can per tonne NOx

Case A: 1988 standards for NOx, CO, and hydrocarbons in effect.
Case B: Additional NOx, CO, and hydrocarbon control is achieved by the development of catalytic converters.

TABLE 9.24

PROJECTED COSTS OF HYDROCARBON EMISSION REDUCTIONS FOR HEAVY DUTY GASOLINE VEHICLES

Year	Total Retail Cost ($m - 1987)		Present Value Total Retail Cost ($m - 1987 $ Can)		Hydrocarbon Emission Reduction (tonne/year)		Present Value of Cost of Hydrocarbon Emission Reduction ($/tonne)(10% discount)	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
1988	0.6	0.6	0.6	0.6	0	0	0	0
1989	0.7	0.7	0.6	0.6	0	0	0	0
1990	0.8	0.8	0.6	0.6	0	0	0	0
1991	0.8	0.8	0.6	0.6	0	0	0	0
1992	0.9	3.8	0.6	2.5	0	0	0	0
1993	1.0	4.1	0.6	2.4	502	502	1,130	4,808
1994	1.0	4.4	0.6	2.3	1,026	1,026	538	2,290
1995	1.1	4.7	0.5	2.3	1,569	1,569	341	1,451
1996	1.2	4.9	0.5	2.2	2,116	2,345	244	938
1997	1.2	5.2	0.5	2.1	2,650	3,121	188	678
1998	1.3	5.5	0.5	2.0	3,161	3,890	151	522
1999	1.4	5.8	0.5	1.9	3,648	4,640	125	418
2000	1.4	6.1	0.4	1.9	4,105	5,361	106	346
2001	1.5	6.4	0.4	1.8	4,526	6,039	92	292
2002	1.6	6.7	0.4	1.7	5,422	7,182	73	233
		Totals:	$6.5	$20.2	14,672	17,093		

Case A:
Total Retail Cost: $6.5 $m - 1987 $ Can
Total Hydrocarbon Reduction 14,672 tonnes hydrocarbons
Cost of Hydrocarbon Reduction:
i. 33% of total cost: $149 1987 $ Can per tonne hydrocarbons

Case B:
Total Retail Cost: $20.2 $m - 1987 $ Can
Total Hydrocarbon Reduction 17,093 tonnes hydrocarbons
Cost of Hydrocarbon Reduction:
i. 33% of total cost: $393 1987 $ Can per tonne hydrocarbons

Marginal Cost of Additional Hydrocarbon Control:
Case A - Case B:
Retail Cost Difference: $14 $m - 1987 $ Can
Hydrocarbon Reduction Difference: 2,421 tonnes hydrocarbons
Marginal Cost: $1,874 1987 $ Can per tonne hydrocarbons

Case A: 1988 standards for NOx, CO, and hydrocarbons in effect.
Case B: Additional NOx, CO, and hydrocarbon control is achieved by the development of catalytic converters.

TABLE 9.25

PROJECTED COSTS OF CO EMISSION REDUCTIONS FOR HEAVY DUTY GASOLINE VEHICLES

Year	Total Retail Cost ($m - 1987)		Present Value Total Retail Cost ($m - 1987 $ Can)		CO Emission Reduction (tonne/year)		Present Value of Cost of CO Emission Reduction ($/tonne)(10% discount)	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
1988	0.6	0.6	0.6	0.6	0	0	0	0
1989	0.7	0.7	0.6	0.6	0	0	0	0
1990	0.8	0.8	0.6	0.6	0	0	0	0
1991	0.8	0.8	0.6	0.6	0	0	0	0
1992	0.9	3.8	0.6	2.5	0	0	0	0
1993	1.0	4.1	0.6	2.4	1,028	1,028	552	2,348
1994	1.0	4.4	0.6	2.3	2,062	2,062	268	1,139
1995	1.1	4.7	0.5	2.3	3,101	3,101	173	734
1996	1.2	4.9	0.5	2.2	4,109	5,417	126	406
1997	1.2	5.2	0.5	2.1	5,050	7,756	98	273
1998	1.3	5.5	0.5	2.0	5,942	10,111	80	201
1999	1.4	5.8	0.5	1.9	6,758	12,441	68	156
2000	1.4	6.1	0.4	1.9	7,507	14,698	58	126
2001	1.5	6.4	0.4	1.8	8,187	16,846	51	105
2002	1.6	6.7	0.4	1.7	9,503	19,581	41	86
		Totals:	$6.5	$20.2	28,050	41,916		

Case A:
Total Retail Cost: $6.5 $m - 1987 $ Can
Total CO Reduction: 28,050 tonnes CO
Cost of CO Reduction:
i. 33% of total cost: $78 1987 $ Can per tonne CO

Case B:
Total Retail Cost: $20.2 $m - 1987 $ Can
Total CO Reduction: 41,916 tonnes CO
Cost of CO Reduction:
i. 33% of total cost: $160 1987 $ Can per tonne CO

Marginal Cost of Additional CO Control:
Case A - Case B:
Retail Cost Difference: $14 $m - 1987 $ Can
CO Reduction Difference: 13,866 tonnes CO
Marginal Cost: $327 1987 $ Can per tonne CO

Case A: 1988 standards for NOx, CO, and hydrocarbons in effect.
Case B: Additional NOx, CO, and hydrocarbon control is achieved by the development of catalytic converters.

traps would be available for the 1992 model year HDDV at an additional cost of $500 per vehicle. The total vehicle cost would then be $1107. As for heavy duty gasoline vehicles, this scenario may not be technically feasible in 1992 although research is currently being done on particulate traps for heavy duty diesel vehicles.

The total annual retail costs for Case A and Case B are given in Table 9.26.

9.6.2 Operating Costs

For Case A, fuel consumption is expected to increase by 1%. From the Transport Canada report [4], the fuel consumption of the classes of diesel vehicles was reported to be 15.6 L/100 km for light HDDV, 29.4 L/100 km for medium HDDV, and 39.8 L/100 km for heavy HDDV. Per vehicle, the increased fuel consumption would then be 277 L for light HDDV, 1267 L for medium HDDV, and 1267 L for heavy HDDV.

Using a cost of diesel fuel of $0.45/L and discounting at 10% to 1987, the total 20-year lifetime operating cost per vehicle would be $63.44 for light HDDV, $288.97 for medium HDDV, and $742.55 for heavy HDDV. For model years 1988 to 2002, the present value of the total lifetime fuel cost increase would then be $61,460,000.

In Case B, the particulate traps are assumed to require maintenance every 30000 km at a cost of $50. The total distance travelled by the three different vehicle classes is estimated to be 177700 km for light HDDV, 431100 km for medium HDDV, and 815300 km for heavy HDDV [4]. Trap maintenance would then be required 5 times for light HDDV, 14 times for medium HDDV, and 27 times for heavy HDDV over the lifetime of each vehicle.

The present value of the trap maintenance required in each vehicle's lifetime, discounted at 10% to 1987, would be $127.99 for light HDDV, $345.14 for medium HDDV, and $673.38 for heavy HDDV. For the model years 1988 to 2002 then, the present value of the total lifetime maintenance cost

TABLE 9.26

PROJECTED COSTS OF POLLUTION CONTROL EQUIPMENT FOR HEAVY DUTY DIESEL VEHICLES

Model Year	Total Population	Number of Model Year Trucks	Retail Cost ($m - 1987 $ Can)	
	Heavy Duty Vehicles - Diesel		Case A ($607/vehicle)	Case B ($1107/vehicle)
1984	29600	2572		
1985	32602	3164		
1986	35994	3899		
1987	39678	4050		
1988	42875	4713	2.9	2.9
1989	46238	5230	3.2	3.2
1990	49600	5747	3.5	3.5
1991	52963	6263	3.8	3.8
1992	56325	6780	4.1	7.5 *
1993	59688	7297	4.4	8.1 *
1994	63051	7814	4.7	8.7 *
1995	66413	8330	5.1	9.2 *
1996	69776	8847	5.4	9.8 *
1997	73138	9364	5.7	10.4 *
1998	76501	9881	6.0	10.9 *
1999	79864	10397	6.3	11.5 *
2000	83226	10914	6.6	12.1 *
2001	86589	11431	6.9	12.7 *
2002	89952	11948	7.3	13.2 *

Note: *:The additional $500 per vehicle became effective in 1992.

Case A: 1988 standards for NOx and particulates in effect.

Case B: Additional particulate control is gained through the use of particulates traps.

would be \$61,020,000. Adding the extra fuel costs required to operated these vehicles, \$61,460,000, would mean that the total operating costs for HDDV will be \$122,480,000 (1987 \$ Can).

The projected operating costs for Case A and Case B for HDDV are tabulated in Tables 9.27 and 9.28.

9.6.3 Projected Emission Reductions

NO_x and particulates were the only emissions of concern with heavy duty diesel vehicles. In Case A, the future emission levels of NO_x and particulates were based on the 1988 standards. Emission rates of NO_x and particulates were obtained from the Transport Canada report [4]. Engine modifications were used to attain the NO_x and particulate emission standards.

In Case B, it is predicted that particulate traps will be available for heavy duty diesel vehicles for the 1992 model year. The traps were assumed to be 80% efficient in removing particulates. These traps would have no effect on the NO_x emission rates so that the NO_x emission levels would then be then the same as for Case A.

Case C is the base case in which the emission levels of NO_x and particulates are unchanged from the pre-1989 levels. This models the effect of not implementing the 1988 standards. Emission rates for NO_x and particulates were again obtained from the Transport Canada report.

The projected emission rates for NO_x and particulates are given in Tables 9.29 and 9.30.

TABLE 9.27

OPERATING COSTS OF HEAVY DUTY DIESEL VEHICLES

Case A

Model Year	Population	Vehicle Population LHDDV	MHDDV	HHDDV	Total Lifetime Cost (1987 $ Can) (10% discount)
1988	4,713	1,428	1,188	2,097	2,318,183
1989	5,230	1,585	1,318	2,327	2,572,360
1990	5,747	1,741	1,448	2,557	2,826,537
1991	6,263	1,898	1,578	2,787	3,080,714
1992	6,780	2,054	1,709	3,017	3,334,890
1993	7,297	2,211	1,839	3,247	3,589,067
1994	7,814	2,368	1,969	3,477	3,843,244
1995	8,330	2,524	2,099	3,707	4,097,420
1996	8,847	2,681	2,229	3,937	4,351,597
1997	9,364	2,837	2,360	4,167	4,605,774
1998	9,881	2,994	2,490	4,397	4,859,951
1999	10,397	3,150	2,620	4,627	5,114,127
2000	10,914	3,307	2,750	4,857	5,368,304
2001	11,431	3,464	2,881	5,087	5,622,481
2002	11,948	3,620	3,011	5,317	5,876,658
					$61,461,307

Case A: 1988 standards for NOx and particulates are in effect.

TABLE 9.28

OPERATING COSTS OF HEAVY DUTY DIESEL VEHICLES

Case B

Model Year	Population	Vehicle Population LHDDV	MHDDV	HHDDV	Total Lifetime Cost (1987 $ Can) (10% discount)
1988	4,713	1,428	1,188	2,097	2,301,561
1989	5,230	1,585	1,318	2,327	2,553,915
1990	5,747	1,741	1,448	2,557	2,806,269
1991	6,263	1,898	1,578	2,787	3,058,623
1992	6,780	2,054	1,709	3,017	3,310,977
1993	7,297	2,211	1,839	3,247	3,563,331
1994	7,814	2,368	1,969	3,477	3,815,685
1995	8,330	2,524	2,099	3,707	4,068,040
1996	8,847	2,681	2,229	3,937	4,320,394
1997	9,364	2,837	2,360	4,167	4,572,748
1998	9,881	2,994	2,490	4,397	4,825,102
1999	10,397	3,150	2,620	4,627	5,077,456
2000	10,914	3,307	2,750	4,857	5,329,810
2001	11,431	3,464	2,881	5,087	5,582,164
2002	11,948	3,620	3,011	5,317	5,834,519
					$61,020,595
					+ $61,461,307
					$122,481,902

Case B: Additional particulate control is achieved through the development of particulate traps for heavy duty diesel vehicles.

TABLE 9.29

PROJECTED EMISSIONS REDUCTION FOR NOx FROM HEAVY DUTY DIESEL VEHICLES

Year	Projected NOx Emissions Case A (tonne/year)	Case B (tonne/year)	Case C (tonne/year)	NOx Reduction (tonne/year) Case A-C	Case B-C
1984	27,305	27,305	27,305	0	0
1985	30,074	30,074	30,074	0	0
1986	33,203	33,203	33,203	0	0
1987	36,601	36,601	36,601	0	0
1988	39,550	39,550	39,550	0	0
1989	40,110	40,110	42,652	2,542	2,542
1990	40,499	40,499	45,754	5,255	5,255
1991	40,687	40,687	78,856	38,169	38,169
1992	40,950	40,950	51,957	11,007	11,007
1993	41,315	41,315	55,059	13,744	13,744
1994	41,809	41,809	58,161	16,352	16,352
1995	42,730	42,730	61,263	18,533	18,533
1996	43,796	43,796	64,365	20,569	20,569
1997	44,700	44,700	67,767	23,067	23,067
1998	43,065	43,065	70,568	27,503	27,503
1999	44,958	44,958	73,670	28,712	28,712
2000	46,851	46,851	76,772	29,921	29,921
2001	48,744	48,744	79,874	31,130	31,130
2002	50,637	50,637	82,976	32,339	32,339

Case A: Predictions are based on the the 1988 standards; the main change is in the use of engine controls to attain the NOx and particulate emission standards.

Case B: Predictions are based on the assumption that particulate traps are developed for heavy duty diesel vehicles.

Case C: Predictions are based on the assumption that the NOx and particulate emission levels remain unchanged from the pre-1989 levels.

TABLE 9.30

PROJECTED EMISSIONS REDUCTION FOR PARTICULATES FROM HEAVY DUTY DIESEL VEHICLES

Year	Projected Particulate Emissions Case A (tonne/year)	Case B (tonne/year)	Case C (tonne/year)	Particulate Reduction (tonne/year) Case A-C	Case B-C
1984	2,236	2,236	2,236	0	0
1985	2,463	2,463	2,463	0	0
1986	2,719	2,719	2,719	0	0
1987	2,997	2,997	2,997	0	0
1988	3,239	3,239	3,239	0	0
1989	3,424	3,424	3,493	69	69
1990	3,603	3,603	3,747	144	144
1991	3,773	3,773	4,001	228	228
1992	3,943	3,546	4,255	312	709
1993	4,115	3,291	4,509	394	1,218
1994	4,289	3,001	4,763	474	1,762
1995	4,475	2,730	5,017	542	2,287
1996	4,665	2,477	5,271	606	2,794
1997	4,849	2,235	5,525	676	3,290
1998	4,946	1,979	5,779	833	3,800
1999	5,164	1,869	6,033	869	4,164
2000	5,381	1,728	6,287	906	4,559
2001	5,598	1,120	6,541	943	5,421
2002	5,816	1,163	6,795	979	5,632

Case A: Predictions are based on the the 1988 standards; the main change is in the use of engine controls to attain the NOx and particulate emission standards.

Case B: Predictions are based on the assumption that particulate traps are developed for heavy duty diesel vehicles.

Case C: Predictions are based on the assumption that the NOx and particulate emission levels remain unchanged from the pre-1989 levels.

9.6.4 Projected Costs of Emission Reductions

For heavy duty diesel vehicles, the present value of the total retail cost was $30.3 million for Case A and $46.2 million for Case B. In Case A, the retail cost could be divided equally between the NO_x and particulate control. For Case B, however, the additional cost would be due entirely to the particulate control. As a result, the additional retail cost of $16 million would be added to 50% of the total retail cost in Case A for a total cost of $31.0 million.

In Case A, the cost of particulate control was $7001 per tonne, while NO_x control was $143 per tonne. In Case B, the particulate control cost was $4839 per tonne. The marginal cost of the additional particulate control would be $1871 per tonne of particulates removed.

These costs for NO_x and particulate reduction are calculated in Tables 9.31 and 9.32.

9.7 Summary

The total projected costs, capital and operating, for the different vehicle classes are summarized in Table 9.33. The highest total projected costs are for light duty vehicles due to their large population. This group also has the largest reduction in pollutants. Particulate control on HDDV's and LDDV's and NO_x control on HDGV's and LDDV's are particularly costly since the projected pollutant reductions are low.

TABLE 9.31

PROJECTED COSTS OF NOx EMISSION REDUCTIONS FOR HEAVY DUTY DIESEL VEHICLES

Year	Total Retail Cost ($m - 1987)		Present Value Total Retail Cost ($m - 1987 $ Can)		NOx Emission Reduction (tonne/year)		Present Value of Cost of NOx Emission Reduction ($/tonne)(10% discount)	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
1988	2.9	2.9	2.7	2.7	0	0	0	0
1989	3.2	3.2	2.8	2.8	0	0	0	0
1990	3.5	3.5	2.7	2.7	0	0	0	0
1991	3.8	3.8	2.7	2.7	0	0	0	0
1992	4.1	7.5	2.7	4.9	0	0	0	0
1993	4.4	8.1	2.6	4.8	2,542	2,542	1,032	1,881
1994	4.7	8.7	2.6	4.7	5,255	5,255	486	886
1995	5.1	9.2	2.5	4.5	38,169	38,169	65	118
1996	5.4	9.8	2.4	4.4	11,007	11,007	217	396
1997	5.7	10.4	2.3	4.2	13,744	13,744	167	305
1998	6.0	10.9	2.2	4.0	16,352	16,352	135	246
1999	6.3	11.5	2.1	3.8	18,533	18,533	114	208
2000	6.6	12.1	2.0	3.7	20,569	20,569	98	178
2001	6.9	12.7	1.9	3.5	23,067	23,067	83	152
2002	7.3	13.2	1.8	3.3	27,503	27,503	66	121
		Totals:	$30.3	$46.2	105,602	105,602		

Case A:
Total Retail Cost: $30.3 $m - 1987 $ Can
Total NOx Reduction: 105,602 tonnes NOx
Cost of NOx Reduction:
i. 50% of total cost: $143 1987 $ Can per tonne NOx

Case B:
Total Retail Cost: $30.3 $m - 1987 $ Can
Total NOx Reduction: 105,602 tonnes NOx
Cost of NOx Reduction:
i. 50% of Case A cost: $143 1987 $ Can per tonne NOx

Marginal Cost of Additional NOx Control:
Case A - Case B:
Retail Cost Difference: $0.0 $m - 1987 $ Can
NOx Reduction Difference: 0 tonnes NOx
Marginal Cost: ----- 1987 $ Can per tonne NOx

Case A: 1988 standards for particulates and NOx in effect.
Case B: Additional particulate control is gained through the development of particulate traps for heavy duty diesel vehicles.

TABLE 9.32

PROJECTED COSTS OF PARTICULATE EMISSION REDUCTIONS FOR HEAVY DUTY DIESEL VEHICLES

Year	Total Retail Cost ($m - 1987)		Present Value Total Retail Cost ($m - 1987 $ Can)		Particulate Emission Reduction (tonne/year)		Present Value of Cost of Particulate Emission Reduction ($/tonne)(10% discount)	
	Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
1988	2.9	2.9	2.7	2.7	0	0	0	0
1989	3.2	3.2	2.8	2.8	0	0	0	0
1990	3.5	3.5	2.7	2.7	0	0	0	0
1991	3.8	3.8	2.7	2.7	0	0	0	0
1992	4.1	7.5	2.7	4.9	0	0	0	0
1993	4.4	8.1	2.6	4.8	69	69	38011	69315
1994	4.7	8.7	2.6	4.7	144	144	17730	32332
1995	5.1	9.2	2.5	4.5	228	228	10853	19792
1996	5.4	9.8	2.4	4.4	312	709	7658	6145
1997	5.7	10.4	2.3	4.2	394	1,218	5835	3442
1998	6.0	10.9	2.2	4.0	474	1,762	4652	2282
1999	6.3	11.5	2.1	3.8	542	2,287	3892	1682
2000	6.6	12.1	2.0	3.7	606	2,794	3322	1314
2001	6.9	12.7	1.9	3.5	676	3,290	2835	1062
2002	7.3	13.2	1.8	3.3	833	3,800	2186	874
		Totals:	$30.3	$46.2	2,163	6,417		

Case A:
Total Retail Cost: $30.3 $m - 1987 $ Can
Total Particulate Reduction 2,163 tonnes particulates
Cost of Particulate Reduction:
i. 50% of total cost: $7,001 1987 $ Can per tonne particulates

Case B:
Total Retail Cost: $46.2 $m - 1987 $ Can
Additional Retail Cost: $16 $m - 1987 $ Can
Total Particulate Reduction 6,417 tonnes particulates
Cost of Particulate Reduction:
i. 50% of Case A cost: $4,841 1987 $ Can per tonne particulates

Marginal Cost of Additional Particulate Control:
Case A - Case B:
Retail Cost Difference: $16 $m - 1987 $ Can
Particulate Reduction Difference: 4,254 tonnes particulates
Marginal Cost: $1,871 1987 $ Can per tonne particulates

Case A: 1988 standards for particulates and NOx in effect.
Case B: Additional particulate control is gained through the development of particulate traps for heavy duty diesel vehicles.

TABLE 9.33

TOTAL PROJECTED COSTS OF POLLUTION CONTROL SYSTEMS
1988-2002
(1987 $ Can)

Vehicle Class	Case	Pollutant Controlled	Capital Cost ($m)	% of Additional Capital Cost (%)	Operating Cost ($m)	Pollutant Reduction (tonnes/year)	Cost of Reduction ($/tonne)
Heavy Duty Gasoline Vehicle	A	NOx	$2.2	33.0%	$0	543	$4,021
		CO	$2.2	33.0%	$0	28,050	$78
		Hydrocarbons	$2.2	33.0%	$0	14,672	$149
		Total:	$6.5 ($m)		$0 ($m)		
		Capital + Operating Cost:		$6.5 ($m)			
	B	NOx	$6.7	33.0%	$4.3	1,951	$5,655
		CO	$6.7	33.0%	$4.3	41,916	$263
		Hydrocarbons	$6.7	33.0%	$4.3	17,093	$645
		Total:	$20.2 ($m)		$12.9 ($m)		
		Capital + Operating Cost:		$33.1 ($m)			
Heavy Duty Diesel Vehicle	A	NOx	$15.2	50.0%	$30.8	105,602	$435
		Particulates	$15.2	50.0%	$30.8	2,163	$21,221
		Total:	$30.3 ($m)		$61.5 ($m)		
		Capital + Operating Cost:		$91.8 ($m)			
	B	NOx	$15.2	0.0%	$30.8	105,602	$435
		Particulates	$30.9	100.0%	$91.8	6,417	$19,106
		Total:	$46.0 ($m)		$122.5 ($m)		
		Capital + Operating Cost:		$168.5 ($m)			

TABLE 9.33

TOTAL PROJECTED COSTS OF POLLUTION CONTROL SYSTEMS
1988-2002
(1987 $ Can)

Vehicle Class	Case	Pollutant Controlled		Capital Cost ($m)	% of Additional Capital Cost (%)	Operating Cost ($m)	Pollutant Reduction (tonnes/year)	Cost of Reduction ($/tonne)
Light Duty Gasoline Vehicle	A	NOx		$906.8	75.0%	$0	1,308,493	$693
			or	$399.0	33.0%	$0	1,308,493	$305
		CO		$151.1	12.5%	$0	6,865,382	$22
			or	$399.0	33.0%	$0	6,865,382	$58
		Hydrocarbons		$151.1	12.5%	$0	529,591	$285
			or	$399.0	33.0%	$0	529,591	$754
		Total:		$1,209 ($m)		$0		
		Capital + Operating Cost:			$1,209 ($m)			
	B	NOx		$1,267	100.0%	$0	1,511,027	$838
				$759	100.0%	$0	1,511,027	$505
		CO		$655	50.0%	$0	7,619,990	$86
				$903	50.0%	$0	7,619,990	$119
		Hydrocarbons		$655	50.0%	$0	612,081	$1,070
				$903	50.0%	$0	612,081	$1,475
		Total:		$2,577 ($m)		$0		
		Capital + Operating Cost:			$2,577 ($m)			
Light Duty Diesel Vehicle	A	NOx		$20.4	50.0%	$0	5,630	$3,618
		Particulates		$20.4	50.0%	$0	6,531	$3,116
		Total:		$40.7 ($m)		$0		
		Capital + Operating Cost:			$40.7 ($m)			
	B	NOx		$20.4	0.0%	$0	5,630	$3,618
		Particulates		$45.7	100.0%	$0	8,314	$5,491
		Total:		$66 ($m)		$0		
		Capital + Operating Cost:			$66 ($m)			

10.0 TOTAL COSTS OF POLLUTION CONTROL EQUIPMENT: ONTARIO AND CANADA (1984 TO 1988)

Estimates of the total costs of the pollution control equipment used in Ontario and Canada for the last five years, 1984 to 1988, were made and are presented in Tables 10.1 and 10.2. All of the values given are in 1987 Canadian dollars.

For the model years 1984 to 1987, the number of model year cars and trucks in Ontario was obtained from the Registrant/Plate/Vehicle Population Statistics [1] as of December 31, 1987 produced by the Ontario Ministry of Transportation. The total vehicle population in Ontario was obtained from Statistics Canada for the years 1984 to 1987. A linear regression was used to estimate the number of model year cars and the total population of cars in 1988.

A no-catalyst control system was defined as the base case pollution control system for passenger cars and light duty trucks. This system was given a value of $0. For passenger cars, the oxidation catalyst system was given a value of $360 based on the average obtained from various sources. The three-way catalyst system was valued at $640 [36].

Before 1987, 15% of the vehicles had a no-catalyst control system, and 70% used an oxidation catalyst system. The remaining 15% of the passenger cars used a three-way catalyst system. For 1987 and 1988 model year cars, only 5% still used an oxidation catalyst system. The other 95% used three-way catalytic converters [20].

With light duty trucks, the oxidation catalyst system was valued at $225 and the three-way catalyst system was valued at $445. The three-way plus oxidation catalyst system had a value of $510. The values for these systems were obtained from the sources indicated previously in Table 9.1. Before 1987, 16% of the total light duty truck population used a no-catalyst system, 67% used an oxidation catalyst system, 13% used a three-way catalyst

TABLE 10.1

TOTAL COSTS OF POLLUTION CONTROL EQUIPMENT IN ONTARIO (1984-1988)
(1987 $ Can)

Passenger Cars							Total Present Value (10% discount)
Model Year		1984	1985	1986	1987	1988	
Total Population (000's)		3453	3609	3735	3917	4058	
No. of Model Year Cars		433603	476189	526503	453263	499713	
Costs:	($/vehicle)						
No catalyst system (base)	$0	$0	$0	$0	$0	$0	
Oxidation Catalyst ($m)	$360	$109	$120	$133	$8	$9	
3-way catalyst system ($m)	$640	$42	$46	$51	$276	$304	
Total Retail Cost: ($m)		$151	$166	$183	$284	$313	
Present Value (10%) ($m)		$215	$214	$215	$303	$304	$1,252

Light Duty Trucks							
Model Year		1984	1985	1986	1987	1988	
Total Population (000's)		539	643	688	691	766	
No. of Model Year Trucks		72552	72107	83747	83133	88730	
Costs:	($/vehicle)						
No catalyst system (base)	$0	$0	$0	$0	$0	$0	
Oxidation Catalyst ($m)	$255	$12	$12	$14	$1	$1	
3-way catalyst system ($m)	$445	$4	$4	$5	$14	$15	
3-way + oxidation system ($m)	$510	$1	$1	$2	$24	$25	
Total Retail Cost: ($m)		$18	$18	$21	$39	$42	
Present Value (10%) ($m)		$26	$23	$25	$42	$41	$156

Passenger Cars and Light Duty Trucks							
Model Year		1984	1985	1986	1987	1988	
Total Retail Cost: ($m)		$169	$184	$204	$323	$355	
Present Value (10%): ($m)		$240	$238	$240	$345	$345	$1,408

TABLE 10.2

TOTAL COSTS OF POLLUTION CONTROL EQUIPMENT IN CANADA (1984-1988)
(1987 $ Can)

Passenger Cars							Total Present Value (10% discount)
Model Year		1984	1985	1986	1987	1988	
No. of Model Year Cars		971000	975000 *	980000 *	985000 *	990000 *	
Costs:	($/vehicle)						
No catalyst system (base)	$0	$0	$0	$0	$0	$0	
Oxidation Catalyst ($m)	$360	$245	$246	$247	$18	$18	
3-way catalyst system ($m)	$640	$93	$94	$94	$599	$602	
Total Retail Cost: ($m)		$338	$339	$341	$617	$620	
Present Value (10%) ($m)		$481	$439	$401	$659	$602	$2,582
Light Duty Trucks							
Model Year		1984	1985	1986	1987	1988	
No. of Model Year Trucks		273000	275000 *	276000 *	278000 *	279000 *	
Costs:	($/vehicle)						
No catalyst system (base)	$0	$0	$0	$0	$0	$0	
Oxidation Catalyst ($m)	$255	$47	$47	$47	$4	$4	
3-way catalyst system ($m)	$445	$16	$16	$16	$48	$48	
3-way + oxidation system ($m)	$510	$6	$6	$6	$79	$80	
Total Retail Cost: ($m)		$68	$69	$69	$131	$132	
Present Value (10%) ($m)		$97	$89	$81	$140	$128	$534
Passenger Cars and Light Duty Trucks							
Model Year		1984	1985	1986	1987	1988	
Total Retail Cost: ($m)		$406	$408	$410	$748	$751	
Present Value (10%): ($m)		$578	$527	$482	$799	$730	$3,117

(*): estimated value of model year population.

system, while the other 4% used a three-way plus oxidation catalyst system. For 1987 and 1988 model year trucks, only 5% of the trucks still used an oxidation catalyst system. The rest of the trucks used either a three-way catalyst system (39%) or a three-way plus oxidation catalyst system (56%) [20].

The total retail cost for each model year car or light-duty truck was then the sum of the total cost for the three or four alternative systems. The present value, based on the year 1987 and using a 10% discount rate, was calculated for each year and totalled for the past five years. The present value of the total costs for the years 1984 to 1988 was $1252 million for passenger cars and $156 million for light duty trucks. The total cost for passenger cars and light duty trucks was then $1408 million. These costs are shown in Table 10.1.

In order to estimate the total cost of pollution control equipment in Canada, the same procedure was used. The number of model year cars was obtained from estimates made by Transport Canada; they assumed a 0.5% growth rate in motor vehicle sales to provide estimates for model years 1985 to 1988. The same fraction of cars and trucks using the pollution control systems was used as for the Ontario case [20].

The present value of the total costs for the years 1984 to 1988 was $2582 million for passenger cars and $534 million for light duty trucks. The total present value of the pollution control equipment for passenger cars and light duty trucks was then $3117 million. These costs are presented in Table 10.2.

11.0 CONCLUSIONS

In carrying out the tasks assigned by the Air Resources Branch of the Ontario Ministry of the Environment, the following conclusions were determined.

1.0. In 1988, there were about 5 million cars and light duty trucks and about 73,000 heavy duty vehicles being driven in Ontario. By the year 2002, there may be 8 million cars and light duty trucks on the road. These could be joined by as many as 155,000 heavy duty vehicles.

2.0. Other mobile sources of pollutants include other transportation sources (aircraft, railway, and shipping), household facilities (lawnmowers, snowblowers, snowmobiles, and recreational boats), and farm equipment (tractors, harvesters, balers, swathers, and combines).

3.0. Light duty vehicles were the major single mobile source of the pollutants CO (72%), hydrocarbons (44%), and NO_x (54%). Farm equipment was the main source of aldehyde emissions (46%), while other transportation sources was the main source of SO_x (28%). Particulates were mainly emitted by heavy duty diesel vehicles 60%.

4.0. Based on current standards, by the year 2002, the total annual emission levels from all mobile sources of hydrocarbons, SO_x, aldehydes, and particulates will have increased from the 1988 levels by 11%, 17%, and 5% respectively. The total annual emission levels of NO_x are projected to decrease by 11%. It was estimated that CO will remain unchanged.

5.0. To meet the current federal emission standards (Sept. 1987), most gasoline passenger cars will require a three-way catalytic converter as well as electronic feedback control of the fuel feed rate. For diesel passenger cars, electronic controls of the exhaust gas recirculation (EGR) and fuel feed and particulate traps are still being developed. Light-duty gasoline-fueled trucks will require a three-way catalyst system.

6.0. To meet the 1988 emission standards, heavy duty gasoline vehicles require EGR and optimization of engine operation. Oxidation catalytic converters are available for vehicles weighing less than 14,000 lb GVWR. Heavy duty diesel vehicles require injection timing retard, turbocompounding and aftercooling, EGR, and thermal insulation of the engine. Particulate traps are still being developed.

7.0. Although vehicles may be designed to meet the emissions standards, excessive emissions from motor vehicles may result from poor maintenance, engine maladjustments, disabled control systems, and misfueling.

8.0. For light duty gasoline vehicles, the present value of the total capital costs for the years 1988 to 2002 to control NO_x, CO, and hydrocarbon emissions to meet the 1987 emission standards were estimated. The costs were found to be \$693 per tonne NO_x removed, \$58 per tonne CO removed, and \$754 per tonne of hydrocarbons removed (1987 \$ Can).

9.0. For light duty diesel vehicles, the present value of the total capital costs for the years 1988 to 2002 to control NO_x and particulate emissions were estimated to be \$3618 per tonne NO_x reduction and \$3116 per tonne particulate reduction (1987 \$ Can).

10.0. Heavy duty gasoline vehicles must meet the 1988 emission standards for heavy duty vehicles. The total operating and capital costs to control NO_x, CO, and hydrocarbons for the years 1988 to 2002 were estimated to be \$4021 per tonne NO_x, \$78 per tonne CO, and \$149 per tonne hydrocarbon reduction (1987 \$ Can).

11.0. To meet the 1988 emission standards, the total operating and capital costs to control NO_x and particulate emissions from heavy duty diesel vehicles are \$435 per tonne NO_x and \$21,221 per tonne particulates (1987 \$ Can) over the years 1988 to 2002.

12.0. The total cost of pollution control systems on light duty vehicles in Ontario for the years 1984 to 1988 was $1,408 million (1987 $ Can). In Canada, the total cost for these five years was $3,117 million (1987 $ Can).

12.0 BIBLIOGRAPHY

The topic areas interest in this project included:

- the automobile emissions control technology,
- efficiency and cost,
- the levels and effects of vehicle emissions, and
- the effects of tampering on the emissions.

A search was conducted for both light duty and heavy duty gasoline and diesel vehicles. The search utilized both electronic databases as well as traditional methods such as cross-referencing, to locate source information. Literature from:

- Environment Canada,
- Transport Canada,
- Ontario Ministry of the Environment,
- U.S. E.P.A., and
- and other agencies

was searched. The following is a summary of the most relevant references found by source and listed in chronological order.

Environment Canada - The Environmental Protection Service

Control of excessive emissions and fuel consumption by in-use motor vehicles.

EPS 3-AP-81-2.
August 1981.

Even though new cars can meet emission standards with good fuel economy, improper maintenance and tampering lead to excessive emissions and fuel consumption. This report outlines vehicle inspection programs for major centres to ensure that tampering is minimized e.g. carburetors are not

maladjusted by using a rich air/fuel setting. The estimated effects of malfunctions on fuel economy and emissions are listed with tampering rates.

The technology and cost to control automotive emissions in Canada.

IP-8.
January 1984.
Unpublished report.

A detailed examination of the various methods to control automotive emissions of passenger cars and light duty trucks for the previous and current (Sept. 1987) standards is presented. As well, costs for the methods were calculated based on manufacturer's estimates and estimates made by the EPA. Two additional areas considered include the effect of cold weather and fuel composition changes on the emissions from light duty vehicles.

Light duty vehicle emissions and the oxidant issue in Canada.

EPS 2/TS/3.
May 1984.

The major emphasis of this report was on the ozone levels due to the reaction of NO_x and volatile organic carbon (VOC). The conclusion was reached that ozone was best controlled by reducing both NO_x and VOC rather than by reducing just one of the two precursors.

The review of methodologies to evaluate the benefits of lowering the levels of light duty vehicle emissions.

IP-14.
July 1984.
Unpublished report.

The goal of this report was to find a method in the literature to assign a value to the benefits of decreased emission levels by considering health

improvements, increases in crop yield, increases in visibility, and decreases in material deterioration. The report concluded that it was not possible, based on the current literature, to estimate dollar values for any of the possible benefits however.

Air pollution emissions and control: light duty vehicles.

EPS 2/TS/4.
August 1984.

This report projected the decrease in pollutant emissions due to the more stringent standards. A summary of the pollution control systems required to meet the previous and current (Sept. 1987) standards for diesel and gasoline passenger cars and trucks. The expected cost to manufacturers to equip the cars with the extra pollution control devices was $140 (1983 Canadian $).

Analysis of proposed revisions to Canadian light duty vehicle emissions standards.

IP-16.
August 1984.
Unpublished report.

An analysis of the costs and benefits of the revised standards was done. The manufacturers' and consumers' costs due to the addition of the added pollution control device to the vehicles was determined. Costs to the refinery to produce additional unleaded gasoline with and without MMT was also documented. Except for lower car maintenance costs, no values could be assigned to the benefits of reduced emissions. The nonallocative impacts of the new standards, e.g. the effect on international trade, inflation, and employment, was also discussed.

A report with recommendations for the reduction of emissions from in-use light duty motor vehicles.

IP-34.
May 1985.
Unpublished report.

Improper maintenance, tampering, and misfuelling are seen as the major causes of elevated emission levels. A review of the literature provides information on the frequency of engine parameter maladjustment, tampering and misfuelling and their impact on emission levels. Recommendations to reduce the in-fleet emission levels include tamper resistant technology (sealed carburetors, three-way catalyst systems), public awareness programs, anti-tampering and anti-misfuelling legislation, and inspection/maintenance programs.

Automobile misfuelling study: Results of a national public opinion survey.

IP-56.
April 1986.
Unpublished report.

A survey was performed at selected gas stations across the country in order to determine the extent of vehicle misfuelling, how the misfuelling occurs, and the public attitude towards misfuelling.

Air pollution emissions and controls: The effect of control component removal or malfunction on vehicle emissions.

IP-72.
July 1987.
Unpublished report.

Experiments were conducted on Canadian and U.S. specification light duty vehicles to study the most common types of tampering and the effects of the

tampering on vehicle emissions.

Vehicle emissions control system tampering.

EPS 2/TS/6.
March 1988.

The effect of tampering with the emissions control systems is an increase in hydrocarbon, carbon monoxide, and nitrogen oxides emissions. The main culprit is misfuelling. This report describes the various type of tampering which occur, their frequency, and their effects on individual vehicle emissions. Solutions to the problem include anti-tampering/anti-misfuelling legislation, driver/mechanic training programs, and inspection/maintenance programs for urban areas.

Transport Canada.

Analysis of the effects of proposed revisions to light motor vehicle emission standards.

TP 6684.
June 1985.

This is a report of the Socio-Economic Impact Analysis (SEIA) on the effects of the revisions to the allowable emission levels (effective Sept., 1987). The areas considered were the adverse effects of the emissions, automotive emissions control technology, costs of the proposed standards, benefits of the reduced emissions, and nonallocative effects. A cost-benefit analysis was attempted but limited cost information on the value of the benefits limited the usefulness of the analysis.

Analysis of the effects of proposed revision to heavy motor vehicle emission standards.

August 1986.

This report is a SEIA of the effects of the proposed revisions to heavy duty truck emission standards. A description of the emission control technology for heavy duty gasoline and diesel trucks which would allow them to meet the current and proposed standards (effective Dec., 1988) is given. The adverse effects of the emissions, costs, emission reduction benefits, cost effectiveness, and nonallocative effects are considered.

Ministry of the Environment

Exhaust emission surveillance of Ontario in-use cars (brief report).

November 1986.

A test program was started to assess exhaust emissions from 200 in-use cars representing the Ontario car population as of mid-1982. Some of the goals of the program were to provide data for automotive emissions control strategies, to establish a data base of emission factors for air quality modelling, to estimate compliance of Ontario cars with provincial emission criteria and Canadian standards. A fleet of 295 cars of 1962 to 1984 model years were tested

U.S. E.P.A.

Investigations into the emissions effects of vehicle misfuelling.

EPA-AA-IMG-84-3.
April 1984.

This report describes the effect of the amount and frequency of misfuelling on motor vehicle exhaust emissions. Included are the effects of tampering

on exhaust emissions, the comparison of effects on exhaust emissions between low and high altitude emissions, and the effects of continuous misfuelling, and the frequency of misfuelling. For a series of cars, comparisons are made between the exhaust emissions of the original catalytic converter, the converter after being subjected to leaded fuel, and a replacement catalytic converter. The effect of misfuelling on the oxygen sensor was also determined.

Size specific total particulate emission factors for mobile sources.

EPA 460/3-85-005.
August 1985.
Final report.

Particulate emission factors are derived for light duty vehicles and heavy duty trucks using leaded, unleaded, and diesel fuel. The fraction of each vehicle class equipped with the various pollution control devices, the on-road fuel economy, misfuelling rates, and fraction of catalyst systems removed is also estimated.

Cost analysis of particulate emission control technology for heavy-duty diesel vehicles.

ANL/EES-TM-310.
May 1986.

This report describes the particulate trap-oxidizer technology that are currently being developed by the manufacturers for heavy-duty diesel vehicles. An analysis was made of the cost estimates made by the EPA and the manufacturers. It was concluded that the EPA underestimated the life-cycle costs for heavy-duty vehicle particulate traps, while the manufacturers' estimates provided an upper limit on the costs.

In-use performance of Daimler Benz light-duty diesel particulate trap oxidizers.

EPA-AA-SDSB-88-02.
February 1988.
Technical report.

Ten 1980 light duty diesel vehicles equipped with particulate trap oxidizer systems and with mileages between 30000 and 50000 miles were tested for particulate and gaseous exhaust emissions. Only seven of the ten vehicles passed the California standard; there was some evidence of mechanical failure of the trap at low mileage levels.

Other

California State Air Resources Board
Mobile source emissions analysis for California. Vol. 1 & 2.

A2-065-32.
June 1985.

This series of reports identifies market penetration of the pollution control devices, emission rates (including failure conditions), the effect of speed, temperature, and inspection/maintenance programs, and misfuelling on pollution control device systems, and the effect of maintenance of bus smoke and particulates.

i) Forecast of emission control technology and strategy for light-duty vehicles.

June 1985.

Forecasts of the technology used by gasoline-fuelled light duty vehicles are described as well as the strategies used by the various car manufacturers to deal with component failures. The in-use vehicle performance/emissions are

described when malperformances occur.

ii) Technology assessment for light-duty vehicle compliance with a 0.4 g/mile NO_x standard.

June 1985.

An engineering assessment of the technology required to meet a 0.4 g/mile NO_x standard is made. Effects on fuel economy, hardware, and costs are included.

Organization for Economic Co-Operation and Development (OECD).

The cost and effectiveness of automotive exhaust emission control **regulations.**

1979.

This report notes that emission standards are being exceeded as cars age due to degradation of the control systems. The major causes of degradation are control system component durability, improper maintenance, maladjustment, and tampering. The OECD's conclusion is that the most cost effective method to minimize this deterioration would be to impose limits on adjustability of engine parameters to limit tampering. Inspection/maintenance programs are considered to be the least effective of the possible strategies.

U.S. Department of Energy

Effectiveness, benefits, and costs of more stringent nitrogen oxide and particulate emission controls for heavy duty trucks.

ANL/EES-TM-273.

November 1984.

A description of the emission control technology for heavy duty gasoline and diesel trucks is given. Estimates of the cost, benefits, and cost-effectiveness of stringent NO_x and particulate control on a per vehicle

basis is made as well as the impact on fleet sales and mix.

Economics and Public Policy: The Automobile Pollution Case.

Donald N. Dewees.
1974.

A methodology was developed to determine the costs of automobile pollution abatement. A comparison of the cost and effectiveness of the technical alternatives for pollution control was made. Other factors considered included the benefits of pollution abatement, the demand for automobiles, and the effect of engine size, vehicle weight, and fuel composition on pollution.

Automotive Emission Control.

William L. Husselbee.
1984.

This book gives technical details on the design and operation of the different types of pollution control devices currently being used on gasoline passenger cars.

OTHER REFERENCES

These references are considered secondary in usefulness to the study.

Environment Canada

Stopping Acid Rain

This booklet and loose sheets deal mainly with Canadian and US acid rain control programs. Some data are given on the release of SO_2 and NO_x from transportation sources.

Automobile emission trends in Canada 1960 - 1985.

EPS 8-AP-73-1.
May 1973.

This report analyzed the Canadian vehicle population and estimated the effect of the proposed 1975 standards on the total automobile emissions. It is projected that there will be a decrease in Canadian air quality unless controls are used.

Impact of emission standards on energy, vehicle cost, and air quality in Canada: Summary report.

PLMR-21-83.
January 1983.

DuPont analyzed the impact of alternative levels of emission standards on air quality, energy consumption, and economic costs. This report emphasized the increased fuel use required, the increased deterioration rate of the catalytic control systems, and the balance of international trade changes due to increased importation of pollution control systems. DuPont argued for increased standards for CO emissions.

An analysis of the estimated costs and benefits of lead traps relative to conventional muffler systems.

March 1983.
Unpublished report.

This report forecasts sales of vehicles which use leaded gasoline to 1995. A description of lead traps, their cost, and expected emission reductions are given. This analysis was written before the government announced the phase out of lead in gasoline by 1990.

Summaries of studies related to the review of new motor vehicle emission standards.

EPS 2/TS/5.
November 1984.

The executive summaries of eight consultants' studies are given. These studies were commissioned to try to determine the impact of the more stringent emission standards that were to be implemented in Sept. 1987.

Understanding Automobile Emissions
October 1986.

This is a series of papers written jointly by Environment Canada and PACE which describe the emissions of leaded, unleaded, and diesel fuel, pollution control devices (mainly catalytic converter), misfuelling and effects on pollution control devices, effects of automobile emissions, and Federal government initiatives to reduce motor vehicle pollution. These papers are of limited use since they were mainly nontechnical and written for the general public.

U.S. E.P.A.

Medium duty vehicle emission control cost effectiveness comparisons. Vol. 1 - Executive Summary.

EPA 460/3-74-004/a.
January 1974.
Final report.

Emission control cost factors are developed for light duty vehicles - LDV (<6000 lb), medium duty vehicles - MDV (6000-14000 lb), and heavy duty vehicles - HDV (>14000 lb). It was found that MDV control systems are more cost effective than LDV control systems. This report was written in 1974 before catalytic converters were fully developed.

Evaluation of Toyota LCS-M Carina Phase 2.

EPA/AA/CTAB/87-09.
December 1987.

This report deals with testing of emissions from methanol fuelled vehicles.

Other

Environmental Protection Act - Motor Vehicles Regulation RRO. 1980 Reg. 311

Regulations regarding emission standards for hydrocarbons, CO, and visible emissions. Also included is the regulation of the operation of cars containing catalytic converters.

Economic Council of Canada
Automobile emission control: means and costs

1975.

This report deals with technology and costs of automobile emission control. It was based, however, on 1975 data.

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23. **Vehicle Emissions Control System Tampering**. EPS 2/TS.6. Environment Canada - Environmental Protection Service, March 1988.

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30. **Automobile Misfueling Study: Results of a National Public Opinion Survey.** JP-56. Unpublished Report. Environment Canada, Environmental Protection Service, April 1986.

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APPENDIX A

At various stages of the analysis in this report, linear regressions were performed on the data. The resulting regression equations are summarized in the following table.

All the equations are of the form

$$y = mx + b$$

where "m" is the x-coefficient, "b" is the constant term, and "x" is the year. The value of "y" is either

- vehicle population (Tables 2.2, 2.3, 2.4 and 2.5) or
- total annual pollution emissions (Tables 3.2, 3.4, 3.6, 3.8, 3.10, and 3.12).

The r-squared value listed in the table was an indicator of the linearity of the data. Low values, as for model year populations for passenger cars, indicated that the data on which the regression was based did not follow a linear trend. In this particular case, the low r-squared value resulted from the recession in which the sales of model year vehicles decreased and then increased in the range of years considered.

Because of the limited years on which the regressions were based, the equations for vehicle population and emissions are only considered to be valid from the year 1976.

Linear Regression Equations
"Cost Effectiveness of Mobile Source Pollution Control Systems"

TABLES	VARIABLE	CONSTANT TERM	X COEFFICIENT	R SQUARED
2.2	PROJECTED MOTOR VEHICLE POPULATIONS - Light Duty Vehicles			
(9.3)	Passenger Cars - Gasoline			
(10.1)	Total Population	-2.98E+08	151800	0.995
	Model Year Population	-2.12E+07	10929	0.124
(9.4)	Light Duty Trucks - Gasoline			
(10.1)	Total Population	-9.88E+07	50100	0.830
	Model Year Population	-8.54E+06	4338	0.761
(9.12)	Passenger Cars - Diesel			
	Total Population	-4.47E+06	2277	0.995
	Model Year Population	-3.19E+05	164	0.124
(9.13)	Light Duty Trucks - Diesel			
	Total Population	-6.42E+06	3257	0.830
	Model Year Population	-5.55E+05	282	0.761
2.3	PROJECTED MOTOR VEHICLE POPULATIONS - Heavy Duty Vehicles			
(9.18)	Heavy Duty Vehicles - Gasoline			
	Total Population	-4.73E+06	2395	0.998
	Model Year Population	-7.29E+05	368	0.948
(9.25)	Heavy Duty Vehicles - Diesel			
	Total Population	-6.64E+06	3363	0.998
	Model Year Population	-1.02E+06	517	0.947
	Buses			
	Total Population	-2.25E+04	13	0.853
2.4	PROJECTED MOTOR VEHICLE POPULATIONS - Heavy Duty Gasoline Vehicles			
(9.19)	Light Heavy Duty Gasoline Vehicles			
	Total Population	-3.64E+06	1844	0.998
	Model Year Population	-5.61E+05	283	0.947
(9.19)	Medium Heavy Duty Gasoline Vehicles			
	Total Population	-1.09E+06	551	0.998
	Model Year Population	-1.68E+05	85	0.946
2.5	PROJECTED MOTOR VEHICLE POPULATIONS - Heavy Duty Diesel Vehicles			
(9.27)	Light Heavy Duty Diesel Vehicles			
	Total Population	-1.99E+06	1009	0.998
	Model Year Population	-3.07E+05	155	0.947

Linear Regression Equations
"Cost Effectiveness of Mobile Source Pollution Control Systems"

TABLES	VARIABLE	CONSTANT TERM	X COEFFICIENT	R SQUARED
(9.27)	Medium Heavy Duty Diesel Vehicles			
	Total Population	-1.66E+06	841	0.998
	Model Year Population	-2.55E+05	129	0.946
(9.27)	Heavy Heavy Duty Diesel Vehicles			
	Total Population	-2.99E+06	1513	0.998
	Model Year Population	-2.60E+05	233	0.946
3.2	TOTAL ANNUAL NITROGEN OXIDE EMISSIONS FOR ONTARIO FROM MOBILE SOURCES			
	Air	-6.71E+05	341	0.992
	Shipping	-9.61E+05	493	0.230
	Railways	-6.44E+04	48	0.023
	Buses	-3.17E+04	18	0.750
	Snowmobiles	1.17E+04	-6	0.982
	Recreational Boats	-1.19E+05	60	0.853
	Lawnmowers	-6.02E+03	3	0.982
	Snowblowers	-5.23E+03	3	0.947
	Tractors	-1.84E+05	100	0.875
	Combines	1.78E+04	-8	0.887
	Balers	1.27E+04	-6	0.589
	Swathers	1.82E+04	-9	0.317
	Harvesters	1.70E+04	-8	0.463
3.4	TOTAL ANNUAL CARBON MONOXIDE EMISSIONS FOR ONTARIO FROM MOBILE SOURCES			
	Air	-2.17E+06	1107	1.000
	Shipping	-4.15E+05	213	0.264
	Railways	-2.34E+04	17	0.023
	Buses	-8.77E+04	48	0.750
	Snowmobiles	1.14E+06	-567	0.979
	Recreational Boats	-3.14E+06	1612	0.943
	Lawnmowers	-1.86E+06	959	0.984
	Snowblowers	-1.65E+06	840	0.994
	Tractors	-1.63E+06	898	0.886
	Combines	3.23E+05	-152	0.891
	Balers	5.28E+05	-241	0.591
	Swathers	3.77E+05	-183	0.317
	Harvesters	1.71E+04	-8	0.611

Linear Regression Equations
"Cost Effectiveness of Mobile Source Pollution Control Systems"

TABLES	VARIABLE	CONSTANT TERM	X COEFFICIENT	R SQUARED
3.6	TOTAL ANNUAL HYDROCARBON EMISSIONS FOR ONTARIO FROM MOBILE SOURCES			
	Air	-1.47E+06	751	1.000
	Shipping	-2.23E+05	115	1.000
	Railways	-3.51E+04	21	1.000
	Buses	-7.91E+03	4	0.996
	Snowmobiles	7.36E+05	-365	0.979
	Recreational Boats	-6.15E+05	320	0.923
	Lawnmowers	-8.24E+05	425	0.984
	Snowblowers	-7.13E+05	363	0.939
	Tractors	-3.34E+05	184	0.885
	Combines	1.49E+04	-7	0.893
	Balers	2.15E+04	-10	0.565
	Swathers	1.53E+04	-7	0.317
	Harvesters	3.15E+03	-2	0.481
3.8	TOTAL ANNUAL PARTICULATE EMISSIONS FOR ONTARIO FROM MOBILE SOURCES			
	Snowmobiles	3.25E+04	-16.1	0.978
	Lawnmowers	-2.63E+04	13.6	0.986
	Snowblowers	-2.29E+04	11.6	0.943
	Tractors	-1.66E+04	9.1	0.884
	Combines	2.13E+03	-1.0	0.893
	Balers	8.84E+02	-0.4	0.571
	Swathers	3.09E+03	-1.5	0.330
	Harvesters	2.16E+02	-0.1	0.250
3.10	TOTAL ANNUAL SULPHUR OXIDE EMISSIONS FOR ONTARIO FROM MOBILE SOURCES			
	Air	-5.79E+04	29.5	1.000
	Shipping	-1.02E+05	52.3	0.263
	Railways	-1.00E+04	7.4	0.024
	Recreational Boats	-1.36E+04	6.9	0.985
	Tractors	-1.13E+04	6.2	0.878
	Combines	1.49E+03	-0.7	0.855
	Balers	6.68E+02	-0.3	0.519
	Swathers	1.86E+03	-0.9	0.315
	Harvesters	1.77E+04	-8.4	0.472

Linear Regression Equations
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TABLES	VARIABLE	CONSTANT TERM	X COEFFICIENT	R SQUARED
3.12	TOTAL ANNUAL ALDEHYDE EMISSIONS FOR ONTARIO FROM MOBILE SOURCES			
	Railways	-9.36E+02	0.7	0.022
	Snowmobiles	1.09E+04	-5.4	0.981
	Lawnmowers	-7.97E+03	4.1	0.990
	Snowblowers	-6.88E+03	3.5	0.942
	Tractors	-6.55E+03	3.6	0.889
	Combines	6.41E+02	-0.3	0.750
	Balers	6.49E+02	-0.3	0.750
	Swathers	6.20E+02	-0.3	0.355
	Harvesters	6.28E+02	-0.3	0.519

Note: The X- or independent variable is always the year.
The Y- or dependent variable is either vehicle population or emission rate.